ASSEMBLY OF POWER TRANSFORMERS

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Е. Минскер, В. Аншин

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E. Minsker and V. Anshin

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Russian Alphabet with Transliteration

А а	a	Р р	r
Б б	b	С с	s
В в	v	Т т	t
Г г	g	У у	u
Д д	d	Ф ф	f
Е е	e	Х х	kh
Ж ж	zh	Ц ц	ts
З з	z	Ч ч	ch
И и	i	Ш ш	sh
К к	k	Щ щ	shch
Л л	l	Ы ы	y
М м	m	Э э	e
Н н	n	Ю ю	yu
О о	o	Я я	ya
П п	p		

Contents

Introduction 9

Chapter 1. **Transformers** 11

1. The Purpose of the Transformer 11
2. The Primary and Secondary Circuits, E.M.F. and Magnetic Circuit of the Transformer 13
3. The Transformer at no-Load 17
4. The Transformer under Load 21
5. The Losses and Efficiency of the Transformer . . . 24
6. Operation of the Transformer on a Short Circuit . . 26
7. The Effect of the Leakage Fluxes in the Transformer 28
8. The Short-circuit (Impedance) Voltage of the Transformer 30
9. Mechanical Stresses in the Transformer 33
10. Voltage Control in the Transformer 36
11. The Three-phase Transformer 39
12. The Three-winding Transformer 41
13. The Autotransformer. 43
14. Winding Connections and Phase Displacement Groups of Transformers 46
15. The Parallel Operation of Transformers 53
16. Heating and Cooling of the Transformer 58

Chapter 2. **Design Features of Low- and Medium-capacity Transformers** 63

17. Classification, Designations and Performance 63
18. General Design of Transformers 64

19. The Transformer Core 67
20. The Windings and Insulation 73
21. Tapping Switches 79
22. The Leads 87
23. Terminal Bushings 90
24. The Tank, Cooling Gear and Oil Conservator . . . 98
25. Protective Devices and Instruments 105

Chapter 3. **Materials for Transformers** 110

26. Electrical Materials Defined 110
27. Conductor Materials 110
28. Insulation Materials 115
29. Core Materials 122
30. Auxiliary Materials 124

Chapter 4. **Assembly of the Core-coil Unit** (*Stage One*) . . 127

31. General 127
32. Tools for Transformer Assembly 129
33. Unclamping the Top Yoke 134
34. Unblading the Top Yoke 136
35. Preparation for the Assembly of the Core 138
36. Assembly of the Coils on Size 1 and 2 Transformers . 139
37. Packing Out the Coils in Size 1 and 2 Transformers . 144
38. Assembly of the Coils on Size 3 Transformers for up to 35 kV 146
39. Reblading the Top Yoke 157
40. Clamping Up the Core-coil Assembly 160
41. Assembly of the Core-coil Units of the Type ATMK-100/0.5 Moving-coil Voltage Regulator 166
42. Preliminary Tests of the Core-coil Assembly . . . 173

Chapter 5. **Assembly of Leads and Making of Connections on the Core-coil Assembly** (*Stage Two*) 174

43. General 174
44. Soft Soldering of Lead Connections 175
45. Electric Arc Welding 175
46. Electric (Resistance) Brazing 176

47. Crimping 184
48. Cold Pressure Welding (Bonding) 187
49. Argon-shielded Welding 192
50. Manufacture of L. V. Leads 196
51. Manufacture of Leads from Round Wire 202
52. Manufacture of Flexible Connectors 203
53. Joining of Leads to Flexible Connectors 208
54. Assembly of H.V. Leads on Size 1, 6-kV Transformers 210
55. Assembly of H.V. Leads on Size 2, 6-10-kV Transformers 214
56. Assembly of H.V. Leads on Size 3, 35-kV Transformers 216
57. Assembly of L.V. Leads on Size 1 Transformers . . 219
58. Assembly of L.V. Leads on Size 2 Transformers . . 221
59. Assembly of L.V. Leads on Size 3 Transformers . . 222
60. Assembly of Leads on the Type ATMK-100/0.5 Moving-coil Voltage Regulator 225
61. Insulation of Leads 228

Chapter 6. **The Drying of the Core-coil Assembly** 231

62. General 231
63. Drying Conditions 233
64. Drying Equipment 234

Chapter 7. **Assembly of Terminal Bushings** 236

65. Bushing Components 236
66. Preparation of Magnesia Cement 238
67. Assembly of Indoor 6-kV Terminal Bushings . . . 238
68. Assembly of Outdoor 35-kV Terminal Bushings . . . 240
69. Assembly of Terminal Bushings on a Multiple Mounting 241

Chapter 8. **Finishing and Tanking Operations** (*Stage Three*) 243

70. General 243
71. Painting of the Tank, Cover and Conservator . . . 243
72. Preparation of the Tank. 250
73. Tanking of Size 1 Transformers 251
74. Tanking of Size 2 and 3 Transformers 255
75. Tanking in the Case of the Type ATMK-100/0.5 Moving-coil Voltage Regulator 264

76. Final Testing of Transformers 269
77. Dismantling for Despatch 270
78. Final Finishing 272

Chapter 9. **Labour Protection and Accident Prevention** . . . 274

79. Labour Protection in the Soviet Union 274
80. Accident Prevention 275
81. Safety in the Assembly Shop. 275
82. First Aid 277

Index 279

Introduction

The modern transformer is a sophisticated piece of electrical equipment. It consists of a large number of components varying with transformer type, application and capacity. Assembly is the final stage in the manufacture of transformers. Before they come into the assembly department, the transformer components go through a chain of operations in other departments. The principal units that reach the assembly department are the core, the coils, the insulation, the tap-changing (voltage-control) equipment, the tank, the conservator, the terminal bushings, and also the instruments and protective devices.

The assembly of transformers involves a variety of operations, such as the unblading and reblading of the top yoke, assembly of the coils on the core, the assembly and connection of the leads, the application of insulation, etc. The drying of the core-coil assembly, oil-filling, the painting of the tank, etc., are also part of the assembly process.

In view of the multitude of operations coming under the heading "assembly", it is customary to break them down into several stages:

—assembly of the core-coil unit (1st stage);

—assembly of the leads and making of the connections in the core-coil unit (2nd stage);

—tanking (3rd stage).

The objective of the *1st stage* is to put together the core and the coils into a single unit. At this stage, the top yoke is unbladed, the insulation installed, the coils assembled on the limbs, the top yoke rebladed and clamped up. With some transformers, neither the yoke has to be taken apart, nor the coils assembled on the limbs. Instead, steel punchings are inserted into the horizontally placed coils until the core is fully stacked, the yokes clamped, and the assembled core-coil unit is rolled up upright.

The *2nd stage* covers all the operations necessary to assemble the leads and to make the connections in the transformer. Then the core-coil unit with the leads mounted and connected up is placed in a vacuum drier. As a result of the drying operation, the insulation and the coil shrink, the lead and coil clamps work loose. This is why after the drying operation the core-coil assembly is "finished" before it is placed in the tank.

In the *3rd stage*, the transformer fittings and accessories are mounted on the tank cover, the core-coil assembly tanked, and the transformer filled with oil. Then the transformer is handed over to the testing station for tests.

After the test, a nameplate is affixed to the tank, the paintwork touched up, and the transformer shipped to the user.

This brief outline can only give a very scanty idea about the many and diverse operations involved in the assembly of transformers.

The quality and reliability of transformers depend on the knowledge, skills and workmanship of their makers. This is why it is vital for a good transformer assembler to do his job intelligently, to know the purpose and place of every unit in the transformer and to be clearly aware of the consequencies of any departure from the established practices and drawings.

An inherent feature of transformer assembly is that it is difficult or even impossible sometimes to detect before the tests any negligence or a mistake on the part of the assembler by the way he does his job. For this reason, every assembler should know how the transformer operates, its performance characteristics, and the construction of the main units. It is especially important for him to know how the quality of assembly affects the performance, efficiency and reliability of the transformer.

Before we go over to the assembly of transformers, it will be a good thing to discuss why transformers are used, why and how they operate, what parts they consist of, and what materials go to make the parts. Without this, one cannot make a good transformer assembler.

Chapter 1 Transformers

1. The Purpose of the Transformer

Electric energy is mainly generated by fuel-fired (thermal) and hydro-electric stations. Fuel-fired stations produce electrical energy by burning coal or gas, while hydro-electric stations utilize the energy of falling water.

Hydro-electric stations are built where water power resources are available, their construction is technically feasible and economically warranted. Fuel-fired stations are advantageous to build near large deposits of fossil fuel worked on a commercial basis.

As often as not, however, a locality convenient for a hydro-electric or thermal station has very few, if any, factories which would use all of the energy generated, the more so that it is economically more attractive to build big power-generating plants producing large blocks of power.

For full utilization the energy produced has to be transmitted to localities where high demand for it exists—to large industrial centres and districts. Unfortunately, such industrial districts may lie hundreds and thousands kilometres away from power sources. By way of example, the hydro-electric stations on the river Volga in the Soviet Union are several hundred kilometres from the Donets coal fields and the Urals, and a thousand kilometres away from Moscow.

From this follows the need for vast transmission lines between the generating plant and the consumers. It should be remembered, however, that some of the power is inevitably lost due to the heating of the line conductors. Every effort should therefore be made to keep these losses to a minimum.

As will be recalled, the watts lost as heat in conductors are given by

$$P = I^2R$$

where I is the current in the conductors in amperes and R is the resistance of the conductors in ohms.

It is not economical to seek to reduce I^2R losses in conductors by decreasing their resistance R, because this would call for wires of a large diameter (cross-sectional area), i.e., for a greater amount of scarce materials, which is out of the question where great distances are involved. Obviously, a better road to take is to reduce the value of current, the more so that the I^2R losses in a line are proportional to the square of the current. With the current reduced to one-half, one-third or one-fourth, the losses would decrease by a factor of four, nine and sixteen, respectively.

A decrease in the current, however, should not affect the power transmitted over a line; it should remain the same. As is known, power P is equal to current I times voltage V, or

$$P = VI$$

where V is the voltage in volts and I is the current in amperes.

Thus, the transmission of a constant amount of power at a low value of current is possible only if the voltage is increased as the current is decreased. If the current is decreased by a factor of two, three or four, the voltage should be raised two, three or four times, respectively. In other words, for any change in the current and voltage, the product $VI = P$ should remain unchanged.

This leaves us with the obvious choice of a method for decreasing power losses in a transmission line: a reduction in current and an increase in voltage.

For many technical reasons, however, generators cannot be made for very high voltages. Even the biggest units are built for not higher than 15 to 18 kilovolts. This voltage can be used only for power transmission over small distances. Economical power transmission over distances of several hundred or thousand kilometres requires higher voltages (500, 750 kilovolts or higher).

This is where the transformer comes into the picture, a piece of apparatus without moving parts which, by electromagnetic induction, transforms a.c. power at the generator voltage into a.c. power at a voltage convenient for transmission. At the beginning of a power transmission line the voltage is raised by *step-up* transformers. At the end of a transmission line where power is distributed among various consumers (factories, residential areas, etc.), the voltage is lowered by *step-down* transformers to a value convenient for users.

Electric motors, household appliances and lamps are usually made for 127, 220 and 380 volts. At these relatively low voltages power can be used economically, while people can be protected from the danger of electric shock by sufficiently simple means.

To cater for the various groups of users, transformers are built in a great variety of capacities and voltage classes. Existing transformers have capacities from a few volt-amperes to several hundred thousand kilovolt-amperes, while the capacity of all the installed transformers is six to seven times the capacity of the generators producing electric energy.

2. The Primary and Secondary Circuits, E.M.F. and Magnetic Circuit of the Transformer

For its operation the transformer depends on electromagnetic induction. When current is flowing in one of the two windings (say, P in Fig. 1), it sets up an alternating magnetic flux Φ_0 about it. The alternating flux links the S winding, and induces an e.m.f. in it by its rate of change. This is the *e.m.f. of mutual induction.*

If the S winding is connected across a load r, the e.m.f. of mutual induction will give rise to a flow of current through the load, thereby transferring some of the energy to it. The S winding receives this energy by virtue of the magnetic field established by the current flowing in the P winding, while the supply circuit to which the P winding is connected makes up for the energy transferred. Thus, owing to magnetic interlinkage, the energy of the supply circuit is transferred from one winding to the other.

The current flowing in the P winding is called the *exciting or primary current.* It is designated by the letter I_1. The electric circuit containing the supply source, the connecting wires and the P winding is referred to as the *primary circuit.*

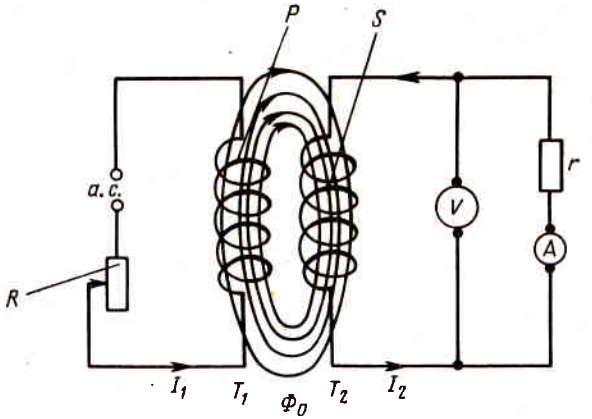


Fig. 1. Magnetic coupling between two coils carrying alternating current:

P—primary coil; S—secondary coil; R—rheostat to control current in primary coil

The magnetic flux links both the S winding and the P winding. For this reason, an e.m.f. is also induced in the P winding. By Lenz's law, this e.m.f. opposes the cause producing it, and for the P winding it will be the *counter-* or *back-e.m.f. of self-induction*, E_1.

The e.m.f. induced in the S winding is known as the *secondary e.m.f.* and is designated by the letter E_2. The circuit connected to this winding is called the *secondary circuit*, and the current flowing around it is referred to as the *secondary current*, I_2. Also by Lenz's law, the secondary current sets up a magnetic flux about the S winding. This flux opposes the primary magnetic flux Φ_0, thereby weakening it.

In order to strengthen the magnetic flux set up by the primary current, the P and S windings are put on a steel core. The steel core (or the *magnetic circuit*, as it is called) strengthens the magnetic flux Φ_0 and, consequently, the secondary e.m.f. E_2 (at a in Fig. 2). Owing to the high permeability of the core, the magnetic flux Φ_0 (at b in Fig. 2) has its path wholly in the core (at a in Fig. 3).

The transformer core may be pictured as consisting of a great number of cylindrical layers which form closed paths in cross section. It may also be pictured that in each of these closed paths linked by a portion of the magnetic flux an e.m.f. and a current are produced.

These are *eddy currents*, so called for the reason that they follow curved paths similar to those of air vortexes. When they flow in the transformer core, eddy currents heat it, thereby causing waste of some of the energy supplied by the source to the primary winding. For this reason, they are also called *parasitic currents.*

If the transformer core were made solid, its resistance would be low, and eddy currents would grow to a high value, involving heavy losses of power (the *eddy-current loss*). This is why every effort should be made to reduce them. Although eddy currents cannot be eliminated completely, they can be kept to a minimum, so that the core is heated but little.

This can be done by reducing the e.m.f. induced in the core and by increasing the resistance of the core, because $I = E/R$. The e.m.f. in the core is reduced by building up the core with thin steel laminations insulated one from another by varnish, paper or glass. In this way the total thickness l of a solid core is divided into thin layers of thickness dl. The laminations (also called punchings or stampings) are arranged to be parallel with the lines of magnetic force (as at b in Fig. 3). In this way the length of the closed paths in which e.m.f.s and eddy currents are set up is sharply reduced. Referring to the figure, the eddy currents *2* circulate in each separate lamination without flowing through the entire thickness of the core.

Because of the reduced e.m.f. and the increased resistance of the core, the eddy currents are decreased. To reduce them still more, silicon is added to transformer steel. The addition of silicon increases the resistivity of the steel without impairing its magnetic properties.

Eddy currents are not the only cause of heat dissipation in the core. A further cause is the reversal of the magnetism of the core due to the continuous variations of the

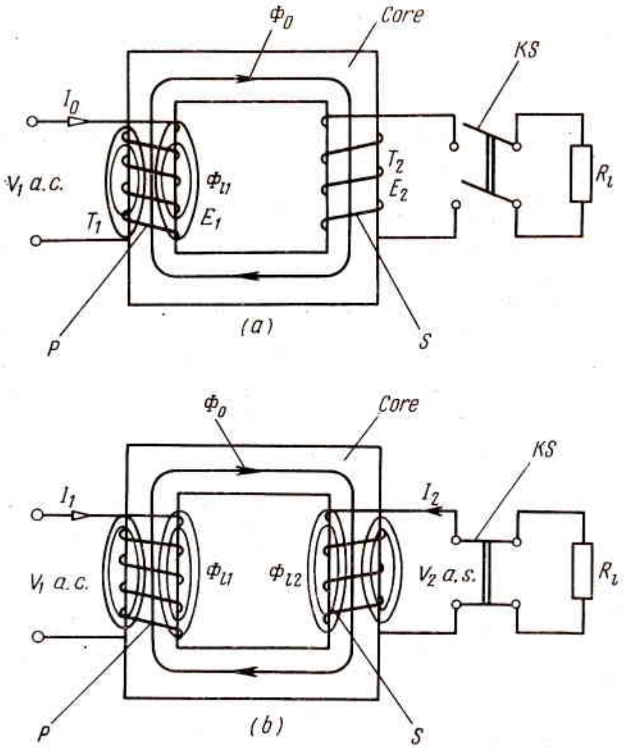


Fig. 2. Primary and secondary windings on a steel core:

a—at no-load (with secondary coil open-circuited); *b*—under load (with secondary coil closed); *P*—primary winding; *S*—secondary winding; *KS*—knife-switch

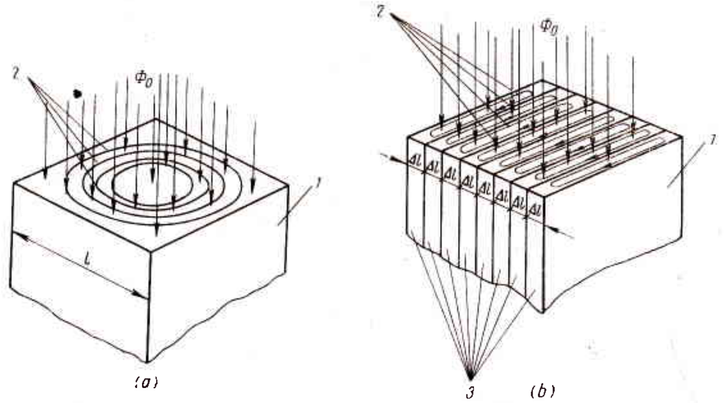


Fig. 3. Eddy currents in the core:

a—solid core; *b*—laminated core; *1*—core; *2*—eddy currents; *3*—core laminations

magnetizing current both in magnitude and direction. The losses of power in the transformer core due to reversal of magnetism are called the *hysteresis loss*.

3. *The Transformer at no-Load*

The operation of the transformer at no-load can be conveniently studied on a model of a single-phase transformer (at *a* in Fig. 2) in which the primary *P* and the secondary *S* are placed on separate cores.

Referring to the figure, an alternating voltage is impressed on the primary, and the secondary is open-circuited. In a practical transformer, this may happen when the primary is connected to the supply line, while the load supplied by its secondary is disconnected. The primary is traversed by current I_0, while no current is flowing in the secondary, because the secondary circuit is opened. This is the *operation of a transformer at no-load*.

The current I_0 flowing in the primary sets up in the core a magnetic flux Φ_0 which is a sinusoidal function of time. The current I_0 taken by the primary winding when the secondary winding is open-circuited is called the *no-load* or *exciting current* of a transformer, and the magnetic flux Φ_0 is known as the *main* or *mutual magnetic flux*.

Since the alternating magnetic flux Φ_0 links both windings of the transformer, it induces an e.m.f. in each, the one in the primary being the counter-e.m.f. of self-induction E_1, and that in the secondary the e.m.f. of mutual induction E_2. The effective or r.m.s. values of these e.m.f.s are given by

$$E_1 = 4.44 f T_1 \Phi_{0max} \, 10^{-8} \text{ volts}$$

$$E_2 = 4.44 f T_2 \Phi_{0max} \, 10^{-8} \text{ volts}$$

where T_1 and T_2 = number of turns in the respective windings

f = frequency in cycles per second

Φ_{0max} = maximum value of the mutual magnetic flux.

Dividing E_1 by E_2 gives

$$\frac{E_1}{E_2} = \frac{T_1}{T_2}$$

This ratio expresses one of the principal characteristics of a transformer: the e.m.f. induced in each of the transformer windings is proportional to its respective number of turns.

The *turns ratio* $T_1/T_2=k$ is also called the *transformation ratio* of a transformer. If the generated voltage is to be stepped up 10, 100 or 1,000 times, the transformer windings should be so made that the secondary winding has 10, 100 or 1,000 times as many turns as the primary winding. Then the secondary winding will be the *H.V.* (*high-voltage*) winding, and the primary winding will be the *L.V.* (*low-voltage*) winding. The L.V. side is connected to the supply line, and the H.V. side is connected to the receiver circuit. Conversely, if the supply voltage is to be stepped down, the ratio of the turns in the windings should be reversed, the supply circuit should be connected to the H.V. side, and the receiver circuit to the L.V. side.

Thus, any transformer can operate as either a step-up or a step-down unit. Everything depends on which of the two windings is connected to the supply circuit, and which to the receiver circuit. Irrespective of whether it is an H.V. or an L.V. side, the winding connected to the supply circuit is referred to as the *primary* of a transformer, and the winding connected to the receiver circuit is called the *secondary* of a transformer.

In the transformer model of Fig. 2 (*a*) and (*b*), the supply voltage V_1 is impressed on the *P* winding of turns T_1, so it is the primary. The load R_l takes its current from the *S* winding of turns T_2, and it is the secondary.

So far we have dealt only with the main or mutual magnetic flux Φ_0. However, there also exists a leakage magnetic flux Φ_{l_1} whose path is partly in air and which links only the primary turns T_1. Since the path of the leakage flux is partly in air, its magnitude is proportional to current which, in our case, is the no-load current I_0. Consequently, the leakage flux Φ_{l_1}, is alternating, as is the current I_0, and induces an e.m.f. of self-induction E_{l_1} in the primary by its rate of change.

To sum up, two e.m.f.s are induced in the primary of a transformer: E_1 by the main magnetic flux and E_{l_1} by the leakage flux.

An e.m.f. of self-induction always opposes the impressed voltage, and its effect on the current in a circuit is equivalent to that of an *inductive* reactance X.

If the exciting current is to be maintained constant, the impressed voltage V_1 should be sufficient to overcome the resistance R_1 of the primary and to produce these e.m.f.s of self-induction. In other words, the impressed voltage V_1 should be equal to the sum of several components: the e.m.f. of self-induction E_1 due to the main flux Φ_0, the e.m.f. of self-induction E_{l_1} due to the leakage flux Φ_{l_1}, and the resistance voltage drop I_0R_1, or in vector form:

$$\dot{V}_1=\dot{I}_0R_1+(-\dot{E}_1)+(-\dot{E}_{l1})$$

The "—" sign in the last two terms on the right side of the equation implies that the e.m.f.s of self-induction oppose the impressed voltage V_1. This relationship can be conveniently studied by means of a vector diagram. Let us construct the no-load vector diagram of a transformer.

As will be recalled, vectors can be used to represent any sinusoidal quantities. In our case such quantities are the impressed voltage V_1 and the magnetic flux Φ_0. Owing to the magnetic saturation of the core, hysteresis and eddy currents, the current I_0 is not sinusoidal. For approximate calculations, however, it is substituted for by a sinusoidal current with the effective or r.m.s. value of I_0. Therefore, it can be represented by a vector as other sinusoidal quantities. As a rule, vector diagrams give the effective or r.m.s. values of variable quantities.

To go back to the no-load vector diagram of a transformer. First, the vector of the magnetic flux Φ_0 is drawn on the horizontal axis (Fig. 4). The flux is set up by the current $\dot{I}_0$ which leads the flux Φ_0 by an angle δ called the *loss angle*, due to the hysteresis loss in the core.

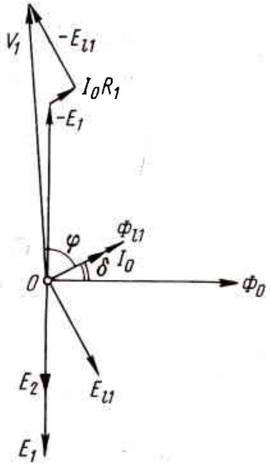


Fig. 4. No-load diagram of a transformer

As it links the turns T_1 and T_2, the magnetic flux $\dot{\Phi}_0$ induces in each the e.m.f.s $\dot{E}_1$ and $\dot{E}_2$ which are in quadrature with (90° behind) the magnetic flux. Apart from $\dot{\Phi}_0$, the current $\dot{I}_0$ sets up the leakage flux $\dot{\Phi}_{l1}$ proportional to and in phase with the current. The leakage flux links T_1 to induce an e.m.f. of self-induction $\dot{E}_{l_1}$ in it.

As stated above, the impressed voltage V_1 should make up for both $\dot{E}_1$ and $\dot{E}_{l_1}$, and the resistance voltage drop $\dot{I}_0R_1$.

We draw on the diagram the vector $-\dot{E}_1$ equal in magnitude and opposite in direction to the e.m.f. $\dot{E}_1$, and add at the end of the vector $-\dot{E}_1$ the vector $\dot{I}_0R_1$ which is in the same direction as the current $\dot{I}_0$. Then the vector $\dot{I}_0R_1$ is extended by a vector equal in magnitude and opposite in direction to the e.m.f. $\dot{E}_{l_1}$. The impressed voltage $\dot{V}_1$ will be equal to the vectorial sum of these quantities. In the diagram it can be obtained by connecting the point O and the end of the vector $-\dot{E}_{l_1}$. What we have obtained is the no-load vector diagram of a transformer.

At no-load the secondary is open-circuited, so no current is flowing in it, and it takes no active power. At the same time, the primary draws from the generator both some reactive (magnetizing) power which is returned to the generator, and some active power.

A small portion of the active power is wasted as heat in the primary; this portion is proportional to the resistance of the winding and the square of the exciting (no-load) current, or $I_0^2R_1$. However, the resistance R_1 of the primary and the current I_0 are usually small (the no-load current is 3 to 10 per cent of the full-load current of a transformer). Therefore, very little active power is lost in the primary. The bulk of the active power is wasted as the hysteresis and eddy-current losses in the core (the *iron loss*). Both the $I_0^2R_1$ loss due to the no-load current and the iron loss are included in the *no-load losses* of a transformer.

Given a constant applied voltage V_1, the no-load loss is independent of the load on the transformer, since the main portion, the iron loss, is determined by the main magnetic flux Φ_0 whose magnitude is practically independent of the load. In other words, the no-load loss (at constant V_1) is a constant loss in a transformer; it exists in any operation of the transformer and is independent of its load. This will become especially clear after an examination of the operation of a transformer under load.

4. *The Transformer under Load*

When the secondary circuit of a transformer (see Fig. 2,*b*) is completed through a load, the transformer is said to be operating under load.

As soon as the knife-switch is closed, a load current I_2 begins to flow around the secondary circuit. As any varying current, this current produces an alternating magnetic flux of its own, consisting of two components. The greater portion of the flux Φ_2 has its path in the core, while the smaller portion of the flux Φ_{l_2} has its path in air and around the secondary winding; this is a leakage magnetic flux.

By Lenz's law, the current induced in the secondary opposes its cause, i.e., it opposes the current I_0. For the same reason, the magnetic flux Φ_2 due to it opposes the flux Φ_0. In other words, the flux due to the secondary current tends to nullify the main magnetic flux Φ_0.

As soon as the flux Φ_0 decreases, however, the e.m.f. of self-induction E_1 in the primary also decreases. Since this e.m.f. opposes the applied voltage V_1 (Fig. 4), an increase or a decrease in it will decrease or increase the primary current. This is borne out by the expression for the primary voltage:

$$\dot{V}_1 = \dot{I}_0R_1 + (-\dot{E}_1) + (-\dot{E}_{l1})$$

whence

$$\dot{I}_0 = \frac{\dot{V}_1 - (-\dot{E}_1) - (-\dot{E}_{l1})}{R_1}$$

If we assume that the flux in the core decreases, E_1 will also decrease, and the primary current will increase. This increase in the primary current over the no-load current will be great enough to produce an extra magnetic flux Φ_1 which exactly neutralizes the flux Φ_2 in the secondary.

In other words, the fluxes Φ_1 and Φ_2, nearly exactly opposite to each other, cancel one another, and the resultant flux Φ_0 induces the e.m.f. E_1 in the primary which balances almost all of the applied voltage V_1. If V_1 remains constant, the e.m.f. E_1 does not change either, and the magnetic flux Φ_0 remains practically unchanged under any load (currents I_1 and I_2) on the transformer. To sum up, as the secondary current in a transformer increases from zero to I_2, the primary current automatically rises from I_0 to I_1.

Similar events occur when the secondary current decreases. Indeed, as the current I_2 decreases, the flux Φ_2 also decreases, and so does its opposition to the flux Φ_0. It would seem that Φ_0 should increase in magnitude. However, an increase in Φ_0 causes an increase in the e.m.f. E_1, i.e., a decrease in the primary current I_1. The latter decreases just enough for the extra flux Φ_1 it produces to balance the changed magnetic flux Φ_2.

The conclusion that can be drawn from the above observations is that the current I_1 supplied by the source to the primary varies exactly as the load, or the current I_2, taken by the external circuit (the load) from the secondary. It is owing to this automatic change in the primary that energy is transferred from one winding to the other electromagnetically.

When a transformer operates under load, the secondary is an energy source. As in the case of any energy source, the following equation applies to the secondary:

$$\dot{E}_2 = \dot{V}_2 + \dot{I}_2 R_2 + \dot{I}_2 X_2$$

where $\dot{E}_2$ = secondary e.m.f.
$\dot{V}_2$ = voltage at the terminals of the secondary
$\dot{I}_2 R_2$ = resistance voltage drop across the secondary
$\dot{I}_2 X_2$ = reactive voltage drop across the secondary.

We shall now construct a vector diagram for a transformer loaded by a resistive load (see Fig. 2,*b*). We draw the vector of the magnetic flux $\dot{\Phi}_0$ on the horizontal axis, and construct the vector of the current $\dot{I}_0$ and the vectors of the e.m.f.s $\dot{E}_1$ and $\dot{E}_2$ lagging 90° behind the vector $\dot{\Phi}_0$ (Fig. 5).

The secondary terminal voltage $\dot{V}_2$ under load is less than the e.m.f. $\dot{E}_2$ by the voltage drop across the winding. Therefore $\dot{V}_2$ can be obtained by subtracting from $\dot{E}_2$ vectorially the resistance drop $\dot{I}_2 R_2$ and the reactive drop $\dot{I}_2 X_2$ which balance the e.m.f. $\dot{E}_{l_2}$ produced by the leakage flux.

Since the transformer operates into a resistive load (say, a lighting load), the current I_2 is in phase with the voltage V_2.

The current I_2 sets up a leakage flux Φ_{l_2} which has its path partly in air and partly through the turns T_2. For this reason, it is in the same direction as the current. The leakage e.m.f. E_{l_2} lags 90° behind the flux.

To obtain a vector diagram for the primary, the vector of the no-load current should be added to the vector of the current $\dot{I}_1'$. This is the current which produces the extra flux Φ_1 balancing the flux Φ_2 of the secondary. With the vector of the total current $\dot{I}_1$ thus obtained, the vector diagram of the primary is then constructed exactly as at no-load.

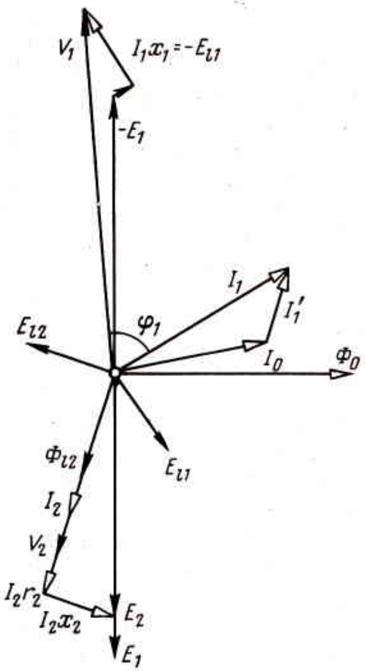


Fig. 5. Vector diagram of a transformer loaded with a resistive load

In our example, we have examined the vector diagram of a transformer supplying a resistive load. The same reasoning will apply to other loads (inductive reactance or impedance).

5. The Losses and Efficiency of the Transformer

As distinct from electrical machines, the transformer has neither rotating parts nor mechanical losses. There are only heat losses in the copper and the core:

$$\Sigma P = P_{iron} + P_{copper}$$

Indeed, we have seen that at no-load the active power taken by the transformer goes only to supply the loss in the copper of the primary and the loss in the core. We have also noted that the iron loss is constant at any load on the transformer, because it is determined by the main magnetic flux Φ_0 which remains unchanged with any load (currents I_1 and I_2) on the transformer.

On the other hand, the copper loss is a variable quantity. It is proportional to the square of the current and the resistance of the winding:

$$P_{copper} = I^2R$$

Naturally, changes in the load affect the copper loss. If a transformer operates at 70 per cent load, the copper loss will only be $0.7^2 = 0.49$ of the design loss. Since the power demand during the day varies (lighting in the daytime and at night, operation of machine tools in different shifts, etc.), the load loss (i.e., the loss determined by the current in the windings) may vary considerably. For a constant primary voltage the iron loss is constant. Therefore, when we speak about reduction in the transformer loss, we have in mind above all the iron loss in the transformer.

The iron loss may be reduced in two ways. The first way is to reduce the magnitude of the magnetic flux Φ_0 (or the induction B), which is not advantageous, since for the same e.m.f.s to be obtained a greater number of turns would have to be provided in the windings, or more copper would have to be used. Therefore, a better way is to use alloy steels for the core, which have an increased resistance (in order to reduce the eddy-current loss) and a smaller hysteresis loss. The eddy-current loss is also greatly reduced by making laminated cores, with laminations insulated from one another.

The alloy steels currently used in the manufacture of transformer cores are sensitive to mechanical treatment. They lose much of their useful properties due to impacts, cold working and other mechanical injuries. This is why the core loss in an assembled transformer is 15 to 20 per cent greater than in the steel prior to working.

Since the transformer has no rotating parts and special materials go to make its main components (copper and aluminium for the windings and alloy steels for the core), the efficiency of transformers is fairly high, ranging between 80 and 99 per cent.

The efficiency of a transformer is given by

$$\text{per cent efficiency} = \frac{P_2}{P_1}100 = \frac{P_2}{P_2 + \Sigma P}$$

where $P_2 = V_2I_2\cos\varphi_2$ = useful power available at the secondary terminals of a transformer

$P_1 = V_1I_1\cos\varphi_1$ = power taken by the primary

$\Sigma P = P_{iron} + P_{copper}$ = losses in a transformer.

As follows from $P_2 = V_2I_2\cos\varphi_2$, the useful power of a transformer depends on both the magnitude and the character of the load (resistive, reactive, etc.), i.e., on the value of $\cos\varphi$ (in our case $\cos\varphi = 1$, because the secondary supplies a purely resistive load).

As the manufacturer does not know the $\cos\varphi$ of the receivers a given transformer is to supply, the nameplate of the transformer always gives its kVA rating (the apparent power):

$$P_2 = V_2I_210^{-3}(\text{kVA})$$

where V_2 and I_2 are the rated (or marked) values of the secondary voltage and current.

In view of the high efficiency of transformers and neglecting, for this reason, their losses, the apparent power for the primary and the secondary may be given by:

$$P_1 = P_2 \text{ or } V_1I_1 = V_2I_2$$

Dividing the last equality by V_1I_2 gives

$$\frac{V_1I_1}{V_1I_2} = \frac{V_2I_2}{V_1I_2}$$

or

$$\frac{I_1}{I_2}=\frac{V_2}{V_1}$$

As will be recalled, the voltages across (or the e.m.f.s in) the windings are proportional to the respective number of turns:

$$\frac{V_2}{V_1}=\frac{T_2}{T_1}$$

As follows from the previous expression, the currents in the windings of a transformer are inversely proportional to the voltages and the number of turns:

$$\frac{V_2}{V_1}=\frac{T_2}{T_1}$$

or

$$\frac{I_1}{I_2}=\frac{T_2}{T_1}$$

6. Operation of the Transformer on a Short Circuit

When a transformer operates on load, its secondary is connected across the resistance R of the energy receivers (see Fig. 2,b). The current in the secondary circuit, I_2, is proportional to the load on the transformer.

When a transformer supplies a great number of receivers, it often happens that for one reason or another the insulation of the connecting wires is damaged. When the wires come in contact at the damaged spot, a *short circuit* occurs.

When the connecting wires from the secondary come in contact with each other at points a and b (Fig. 6), the secondary is also short-circuited. Yet, it continues to take power from the primary and transfer it into the secondary circuit which now consists only of the winding and part of the connecting wires.

At first glance it would seem that on a short circuit the transformer should be destroyed, since the resistance R_2 of the winding and connecting wires is only a small fraction of the resistance R_l of the load. If we assume that the load resistance R_l is, say, 100 times R_2, the current I_{2sc} should also be 100 times I_2.

Since the primary current also increases 100 times ($I_1T_1 = I_2T_2$), the losses in the transformer should sharply increase, namely $100^2 = 10{,}000$ times (I^2R). Naturally, under such conditions the temperature of the windings would

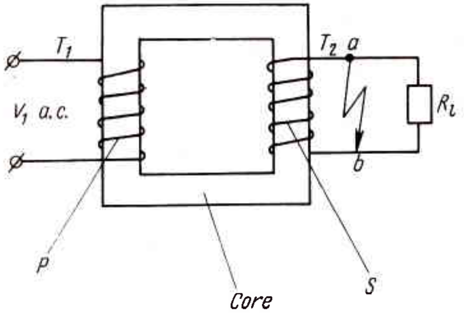


Fig. 6. Short circuit on the secondary side of a transformer:
P—primary; S—secondary;

rise to 500-600°C in a matter of a second or two, and they would burn.

Also there always exist mechanical forces in an operating transformer, which tend to burst the windings radially and axially. These forces are proportional to the product of the currents in the windings, I_1I_2. If, on a short circuit, each of the currents I_1 and I_2 increased 100 times, the forces would increase 10,000 times. They would reach a value of several hundred tons, and the transformer windings would be destroyed in no time.

In actual practice, however, nothing of the kind happens in transformers. As a rule, transformers stand up well to the short-circuit stresses until the short circuit is cleared by their protective equipment. This is because the inductive reactance of a transformer limits the short-circuit current in the windings. This effect of the reactance is related to the leakage magnetic fluxes set up in the transformer.

It is obvious that the leakage flux should increase with increasing current in a winding.

We have already learned that on cutting the turns of the secondary winding the leakage magnetic flux induces in it an e.m.f. of self-induction E_{l_2} which opposes the change in current flow. This effect of the e.m.f. of self-induction in the secondary winding may be pictured as an additional opposition to the short-circuit current.

The secondary e.m.f. E_2 due to the main magnetic flux Φ_0 is equal to the sum of the voltage drops:

$$\dot{E}_2 = \dot{I}_{2sc}R_2 + (-\dot{E}_{l_2})$$

or

$$\dot{E}_2 = \dot{I}_{2sc}R_2 + \dot{I}_{2sc}X_2$$

where

R_2=resistance of the secondary winding (the resistance of the connecting wires may be ignored since it is negligibly small)

X_2=inductive reactance of the secondary winding

$\dot{I}_{2sc}X_2$=reactive voltage equal to E_{l_2} in magnitude.

Experience shows that, depending on the capacity of a transformer, the inductive reactance X_2 is five to ten times as great as R_2. Therefore, the actual current I_{2sc} is only 10 to 20, and not 100, times as great as the normal secondary current I_2 of a transformer. Consequently, the copper loss will increase only 100 to 400 times, and not 10,000 times. The temperature of the windings towards the end of the short circuit (3 to 8 seconds) will reach just 150 to 200°C, and no serious damage can be suffered by the transformer during this short period.

7. The Effect of the Leakage Fluxes in the Transformer

We have seen that owing to the leakage fluxes a transformer is capable of protecting itself from short-circuit currents. Apart from their useful function, however, the leakage fluxes have a detrimental effect on the operation of a transformer. For one thing, the reactive voltage drop I_2X_2 (Fig. 5) reduces the secondary voltage V_2. Consequently, the greater the leakage, the smaller the power available to the energy receiver. For another, the leakage fluxes have their path not only in air but also in the metal parts of a transformer, giving rise to eddy currents and hysteresis

losses in them. These complementary losses, as they are called, are very undesirable, because they increase the total losses and reduce the efficiency of a transformer.

Thus, on the one hand, the leakage fluxes are useful inasmuch as they limit the short-circuit currents and prevent destruction of the transformer; on the other, they have a detrimental effect by reducing the useful power available to the receivers and by increasing the transformer losses.

Transformers are usually built so as to strike a balance between these two conflicting factors. As a way of limiting the leakage fluxes, the primary and secondary coils are placed on a common core a certain distance from each other (Fig. 7), and not on separate limbs, as shown in Fig. 2. Obviously, the greater the distance between the windings,

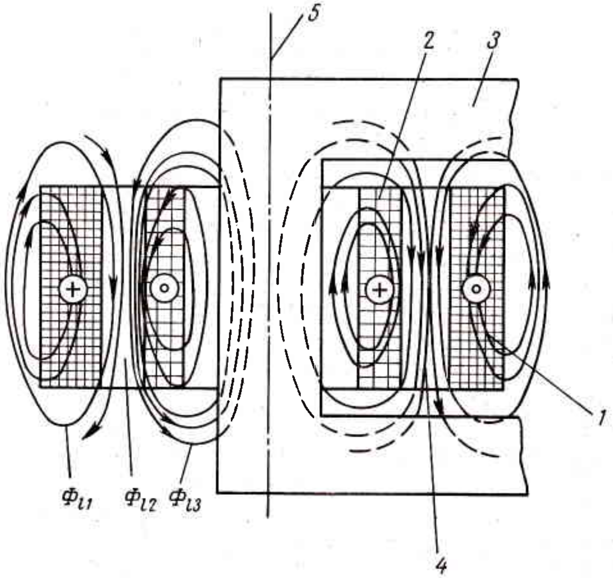


Fig. 7. Arrangement of the primary and secondary windings on a transformer core:

1—primary winding; *2*—secondary winding; *3*—core; *4*—duct between windings; *5*—common axis of core and winding the greater the magnetic leakage, since a greater portion of the magnetic flux will have its path in air. The desired value of leakage flux is obtained by suitably arranging the windings relative to each other and by optimizing their dimensions.

Fig. 7 shows the *concentric* arrangement of the windings. The two coils are placed on a common core so that their geometrical axes coincide with the axis of the core. Referring to the figure, the leakage fluxes Φ_{l_1} and Φ_{l_2} in the duct between the windings add together, giving a total leakage flux.

8. The Short-circuit (Impedance) Voltage of the Transformer

We have learned that the leakage fluxes have a noticeable effect on the operation of a transformer and affect its dimensions and performance. However, it is still unclear how the effect of magnetic leakage can be evaluated.

A direct measurement of magnetic leakage is out of the question, because the leakage magnetic fluxes can take a multitude of paths. Instead, magnetic leakage is evaluated in terms of the effects it has on the voltages across, and the currents in, the transformer windings.

As stated above, on a short circuit the currents in the transformer windings increase only 10 to 20 and not 100 times over their normal values.

Now assume that in a transformer, which has its secondary short-circuited (Fig. 8) and the currents I_{1sc} and I_{2sc} which are 10-20 times the currents I_1 and I_2, the applied voltage V_1 has been reduced. Obviously, the currents in the windings will also decrease. If V_1 be reduced by a factor of 3 to 5, the currents I_{1sc} and I_{2sc} will diminish by the same factor. If V_1 be reduced by a factor of 10 to 20, the currents will again decrease by the same factor. In other words, V_1 can be so adjusted that the currents I_{1sc} and I_{2sc} will be brought down to the normal currents in the respective windings, or $I_{1sc}=I_1$ and $I_{2sc}=I_1$.

The voltage that should be applied to the terminals of one of the windings (while the other is short-circuited) in order to circulate normal currents I_1 and I_2 is called the *short-circuit (or impedance) voltage* of a transformer.

It is designated by the symbol E_z and is usually expressed in per cent of the primary voltage V_1:

$$\text{per cent } E_z=(E_z/V_1)100$$

The value of E_z gives a measure of the leakage fluxes and of their effect on the operation of a transformer.

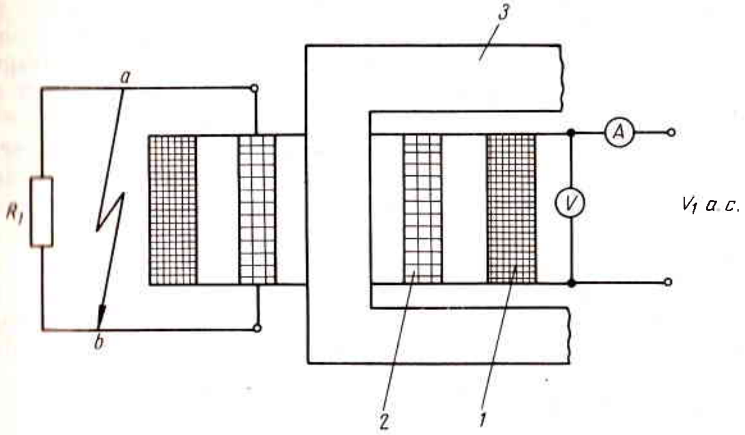


Fig. 8. Short circuit on the secondary side of a two-winding transformer:
1—primary; 2—secondary; 3—core

To show the direct relationship between E_z and magnetic leakage, assume that in a transformer with a certain E_z (say, 5 per cent), the windings have been pushed away from each other by some unspecified means. The ammeter in the primary circuit will immediately read a reduced value of current I_{1sc}, although the voltmeter reads the same applied voltage (5 per cent of V_1). However, it will be other than E_z, because the currents in the windings have become less than their rated values. Obviously, in order to restore their values, the applied voltage should be raised to $E'_z < E_z$ (say, to 8 per cent of V_1). In other words, E_z grows as the spacing between the windings increases.

This effect is not difficult to explain if we recall that an increase in the spacing between the windings builds up the leakage flux which has its path in air. The leakage e.m.f.s E_{l_1} and E_{l_2} increase in proportion, and so does the inductive reactance of the windings. As a result, the currents in the windings diminish, and the applied voltage has to be raised to E'_z in order to circulate rated currents in the windings. By similar reasoning, it may be shown that the impedance voltage decreases with decreasing spacing between the windings.

We have thus shown that there exists a direct relationship between magnetic leakage and impedance voltage. Because of this, all that has been said about the effect of leakage fully applies to impedance voltage, E_z.

The higher the impedance voltage, the smaller the short-circuit current, which fact slows down the temperature rise of the windings carrying the short-circuit current and there is less danger for destructive mechanical forces to develop (for a more detailed discussion the reader is referred to Sec. 9). On the other hand, the higher the impedance voltage, the greater the magnetic leakage, which fact brings about an increase in the transformer losses and in the voltage drop across the windings. As a result, the useful power output and efficiency of the transformer are impaired.

The transformer designer must give careful consideration to the value of E_z. It should be made sufficiently high in order to limit the short-circuit current and to ensure self-protection of the transformer, but not so high as to bring about a noticeable increase in the transformer losses and a decrease in the useful power output.

In the Soviet Union, the values of E_z for each particular transformer size are specified by a relevant USSR State Standard. For transformers with a capacity of 10 to 6,300 kVA, it is 5 to 7.5 per cent. For transformers above 6,300 kVA, it is anywhere between 8 and 11 per cent, depending on the kVA rating and voltage of the H.V. winding.

If the value of E_z is known, it is easy to determine the short-circuit current of the winding. Indeed, I_{1sc} will be as many times the rated current I_1, as the primary voltage V_1 is greater than E_z, or

$$I_{1sc} = I_1 \frac{V_1}{E_z}$$

Since E_z is usually expressed as a percentage of V_1 we got:

$$I_{1sc} = I_1 \frac{100}{\text{per cent } E_z}$$

Thus, if $E_z = 5$ per cent, then I_{1sc} is 100 : 5 = 20 times the rated current I_1.

9. Mechanical Stresses in the Transformer

As has been noted, the operation of a transformer on a short circuit entails destructive mechanical stresses which tend to burst the windings radially and axially. Such stresses, although of a much smaller magnitude, also exist in any transformer under normal operating conditions. Let us examine the cause of these stresses in greater detail.

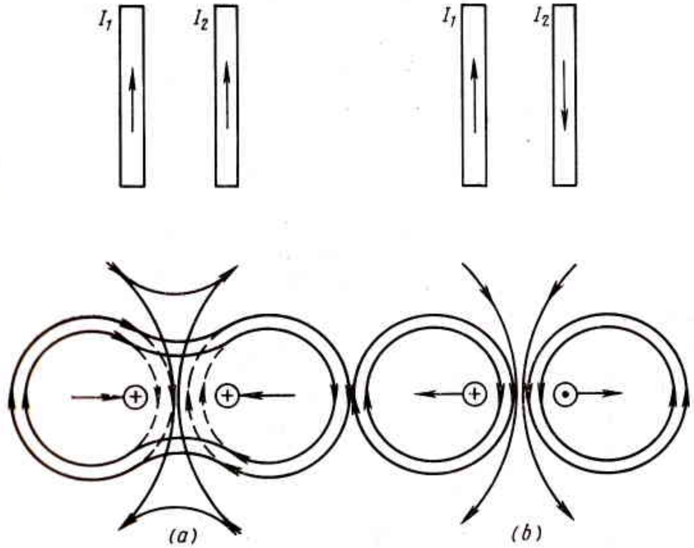


Fig. 9. Mechanical forces acting on conductors carrying current: a—currents in the same direction; b—currents in opposite directions

Consider two parallel conductors placed close to each other (Fig. 9). The conductors at a in Fig. 9 carry currents in the same direction, and at b in opposite directions.

A magnetic field is set up around each of the conductors, with the lines of magnetic force arranged as shown in the figure.

When the currents in the conductors are in the same direction, the flux due to the current I_1, on moving downwards in the space between the conductors, meets the flux due to the current I_2, which moves upwards. The lines of the two fluxes squeeze outwards and form a common flux which moves on a shorter path, causing the conductors to attract.

When the currents are in opposite directions, the lines of both fluxes move in the space between the conductors in the same direction (downwards). The two fluxes combine, causing the conductors to repel and to provide a greater area for the common flux.

In both cases, the conductors attract and repel with a force F which is given by

$$F = kI_1I_2$$

where k is the proportionality factor.

In each winding of a transformer, the current in all of the turns is in the same direction. However, the secondary current I_2 (which is an induced current) is in an opposite direction with respect to I_1, or the primary current. For this reason, the winding conductors both attract and repel in a transformer.

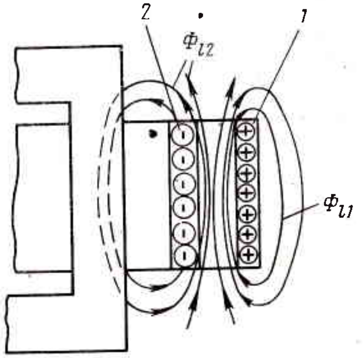


Fig. 10. Leakage fluxes around the windings of a transformer: *1*—primary; *2*—secondary

Fig. 10 shows the leakage fluxes Φ_{l1}, and Φ_{l2} and the directions of the currents I_1 and I_2. The two leakage fluxes combine to form a common flux which causes the turns to attract. At the same time, the fluxes in the duct between the windings, being in the same direction, tend to push the windings away from each other. The bursting force acts both radially and axially, because any turn of one winding is repelled by all the turns in the other.

Consider the turn M of the secondary *2*, Fig. 11 (*a*). The turn m which is on the same horizontal with the turn M acts upon the latter with a force of repulsion F_1 directed radially. At the same time, all the turns of the primary *1*, both above and below the turn m, act upon the turn M with forces of repulsion F_2, F_3, etc. Combining these forces by the parallelogram law gives the resultant force FM which is directed upwards at an angle to the horizontal.

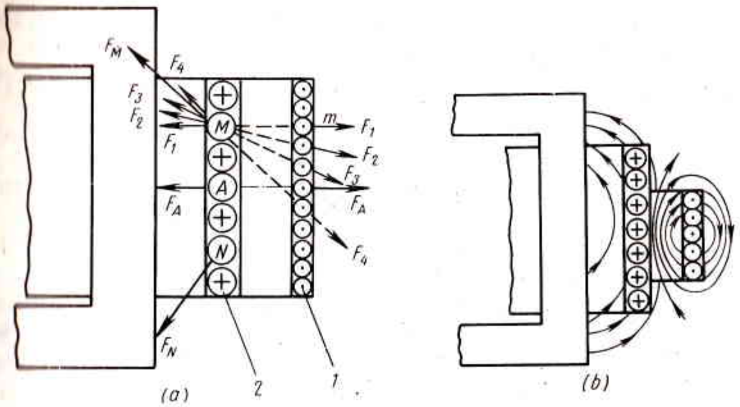


Fig. 11. Mechanical stresses in transformer windings:
a—windings equal in height; *b*—windings differ in height; *1*—primary; *2*—secondary

Similarly we may find that the turn N is acted upon by the resultant force of repulsion F_N, directed downwards at an angle to the horizontal. Only the turn A in the middle of the winding will not be subjected to any axial forces, because the forces of repulsion due to the turns above and below the turn A will give a common resultant force F_A directed radially.

It is obvious that the radial forces (compressing the inner winding and expanding the outer one) will be greatest in the middle of the winding, decreasing towards the periphery. Conversely, the axial forces will be smallest in the middle of the winding, increasing towards the periphery.

Under normal operating conditions, all of these forces in a transformer are negligible. On a short circuit, however, when the primary and secondary currents grow 10 to 20 times (depending on the value of E_z), the forces increase 100 to 400 times. The greatest danger comes from the axial forces which may destroy the windings (especially near the periphery), if they are not strong enough. The effect of axial forces in a transformer is counteracted by various structural features.

The axial forces become particularly great if the windings differ in height. Then, instead of passing through the duct between the windings nearly parallel to the axes of the windings, Fig. 11 (*b*), the leakage fluxes move radially. On sqeezing their way between the turns, they tend to burst the winding.

It should be noted that a transformer may have windings differing in height not only because of negligence on the part of the makers. Provisions are often made in transformers for voltage control by increasing or decreasing the number of active turns in one winding with respect to the other. Then the position of the voltage-control taps will change the relative height of the windings.

10. *Voltage Control in the Transformer*

In most cases, receivers of electrical energy are designed to operate at a certain definite supply voltage. Should the supply voltage change, the normal operation of receivers will be upset. A decrease of 3 to 5 per cent in supply voltage sharply reduces the speed of induction motors, cuts down production output, and adversely affects lighting and operation of radio and TV receivers.

Consider the causes of a decrease in supply voltage in a simple case. Assume that several transformers with a secondary voltage of 220 V are connected to a 6.3-kV circuit. In practice, such transformers will operate continuously under full load but seldom.

At night, when most of the factories are inoperative and the power they take is usually small, the 6.3-kV circuit will carry a small current which will not entail any appreciable voltage drop. As soon as the machine-tools at the factories are started in the daytime, the load on the transformers sharply goes up. The secondary currents in the transformers increase, and so does the primary current taken by each transformer from the supply circuit. Adding together, these currents produce in the 6.3-kV circuit a total current I which is many times greater than at night. Now, the supply voltage will be lower than 6.3 kV. The secondary voltage applied to the receivers will drop by a proportional amount.

However, the receivers need a constant voltage of 220 V, irrespective of any fluctuations in the primary voltage. To meet this demand, provision is made in transformers for voltage control within certain limits.

The most commonly used method of voltage control is to change the number of active turns in one of the windings in steps. When the number of active turns in, say, the primary is increased or decreased, the magnitude of the magnetic flux and, consequently, the secondary voltage also increase or decrease.

In practical transformers, it is usual to provide several *voltage-control taps* on the H.V. winding. Each tap corresponds to a certain number of series-connected turns (Fig. 12).

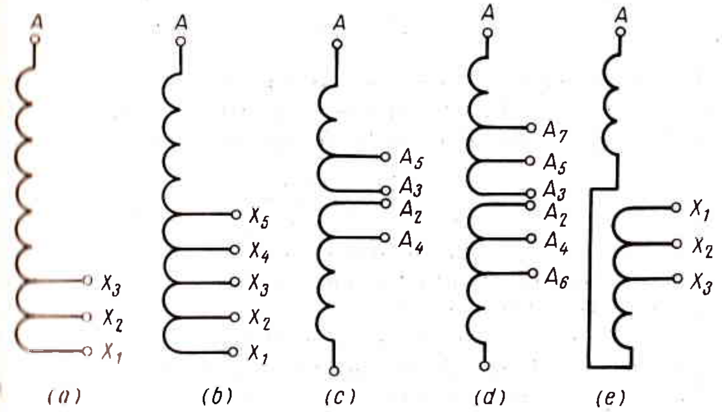


Fig. 12. Voltage control taps on the H.V. winding:
a—three taps at end of winding; *b*—five taps at end of winding; *c*—four taps in middle of winding; *d*—six taps in middle of winding; *e*—reverse connections with three taps at end

Standard low- and medium-capacity transformers (up to 630 kVA) usually have three voltage taps on the H.V. winding. The middle tap, X_2, is the rated-voltage, or principal tap, i.e., through it the transformer can deliver its rated voltage (6.3. kV in our case). Through the other two taps the transformer can deliver a voltage which is within ±5 per cent of the rated value, Fig. 12 (*a*).

Assume that a voltage of 6.3 kV is delivered by 1,000 turns in the H.V. winding (tap X_2). Then a voltage of 6.615 kV, which is 5 per cent above the rated value, will require 1,050 turns in circuit (tap X_1). For a voltage of 5.985 kV, which is 5 per cent below the rated value, there should be 950 active turns in the H.V. winding (tap X_3). Thus, the secondary voltage can be adjusted in steps of 315 V. Each step takes 50 series-connected turns in the winding.

To go back to our example. Assume that due to an increased load the supply voltage drops to 6 kV, or by 5 per cent. The voltage on the L.V. side of the transformers will also drop by 5 per cent or to $220-(220\times 0.05)=209$ V. This drop may seriously impair the performance of the electric motors.

How should the H.V. winding be connected to maintain the secondary voltage at 220 V? We know that

$$\frac{V_1}{V_2}=\frac{T_1}{T_2}$$

If V_1 goes down by 5 per cent, and V_2 must be maintained constant (at 220 V), the number of turns in the primary, T_1, should also be reduced by 5 per cent. Then

$$\frac{0.95V_1}{V_2}=\frac{0.95T_1}{T_2}$$

In other words, if the secondary voltage is to be 220 V, the H.V. winding should be connected to the tap X_3, leaving 950 active turns in it.

By the same reasoning, it is easy to determine the tap to be selected, should the supply voltage rise to, say, 6.6 kV.

Instead of three voltage taps, large-capacity transformers have five taps on the H.V. side, which give a greater number of steps of voltage control, Fig. 12 (*b*).

Voltage taps may be provided either at the ends or the middle of the winding. With the voltage taps arranged at an end of the winding, it may happen as if the winding becomes shorter, especially when the connection is shifted to the tap X_3 or X_5, Fig. 12 (*a*) and (*b*). As stated earlier, the difference in height between the windings results in an increase in the axial forces acting upon the windings. This is why the usual practice is to arrange voltage taps at the middle of the winding, Fig. 12 (*c*) and (*d*), or to use a reverse arrangement, Fig. 12 (*e*), in the case of low-capacity transformers.

End-placed voltage taps on the H.V. side are limited mainly to low-capacity transformers where mechanical forces are negligible, while the mid-winding arrangement is difficult to carry out because of complications in design.

The arrangement of Fig. 12 (*c*) gives ±5 per cent variation of the voltage. In the arrangement of Fig. 12 (*d*), voltage can also be controlled within ±5 per cent, but in steps of 2.5 per cent.

The taps are connected to a ratio adjuster which provides a means of changing taps on the transformer by simply turning the operating handle without having to take down and remake connections.

With the arrangements of Fig. 12, the taps can be changed only with the transformer disconnected from the line, because the ratio adjuster is not intended for operation under load (off-load tap changing). If taps were changed under load, the arc striking between the contacts of the ratio adjuster would quickly destroy them.

Off-load tap changing is sometimes inconvenient, since the receivers have to be de-energized while the connections to taps of the transformer are being changed. This is why many transformers, especially in the large-capacity class, are equipped with facilities for changing taps under load (on-load tap changing). However, such equipment lies outside of the scope of this book.

11. The Three-phase Transformer

So far we have dealt with single-phase transformers. They are widely used in household appliances. Bigger single-phase units are employed in a.c. electric locomotives. Mammoth single-phase transformers for 220 and 500 kV are installed at large thermal and hydro-electric stations.

However, electric energy is never transmitted single-phase. Instead, three-phase systems are now used everywhere. Therefore, most transformers are three-phase units—they handle three-phase power.

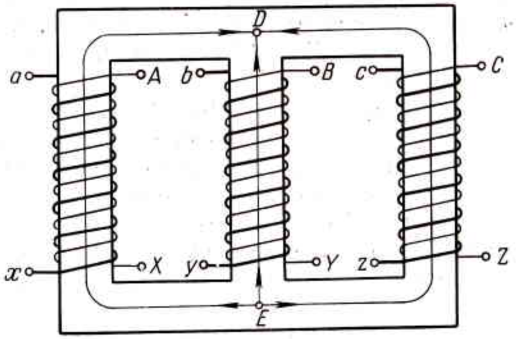


Fig. 13. Diagram of a three-limb transformer

Of course, transformation of three-phase voltage can be accomplished by means of three single-phase units with their primary and secondary connected in a star or in a delta to form a three-phase system. This is how large-capacity single-phase transformers are employed at large generating stations. They have their primaries connected to the respective phases of the generators, and their secondaries to the respective phases of a transmission line.

Alternatively, three single-phase units may be built into a single three-phase unit. The magnetic circuit of such a transformer consists of three limbs held together by yokes at top and bottom (Fig. 13). Each limb carries one primary and one secondary winding. The primaries are connected either in a star or in a delta, and so are the secondaries. Each limb with the associated windings is in fact a single-phase transformer. For this reason, all that has been said about a single-phase transformer fully applies to the individual phases of a three-phase transformer.

In each core of a three-phase transformer there is a magnetic flux produced by the primary current. Since each primary belongs to a particular phase of a three-phase system, the currents in the windings and the applied voltages are three-phase, and so are the magnetic fluxes.

In the previous discussion it was assumed that a magnetic flux should follow a closed path, i.e., on passing through the core it must return to the beginning of the same core. In a three-phase transformer, each of the fluxes circulates only within its own limb, converging at points D and E (Fig. 13) in the middle of the top and bottom yokes. At these points the fluxes add together. Since, however, the fluxes are 120° apart, they combine vectorially. Vectorial addition of the three fluxes results in a zero magnitude, thus eliminating the need for a return path for the flux (provided the load on the phases is balanced), exactly as there is no need for a neutral or return wire in a star-connected system.

It is seen from Fig. 13 that the magnetic path is not the same for all three fluxes, being longer for the outer limbs (phases A and C) than for the inner limb (phase B). As a result, the exciting current is not the same in the three phases, being greater for the outer ones.

12. *The Three-winding Transformer*

The three-phase transformer described in the previous section has two windings on each limb, one primary and one secondary. Such a transformer can change, or transform, one voltage V_1 into another voltage V_2. In some cases, however, a third voltage V_3 has to be provided.

Consider a 20-MVA transformer with a primary voltage of 110 kV which has to supply an adjacent factory and a remote industrial area. The adjacent factory can be conveniently supplied at 6.3 kV. Therefore, the secondary of the transformer is wound for this voltage. However, it is not advantageous to transmit power over a large distance at 6.3 kV, because much energy would be lost. As a way out, a third winding is added to each limb, wound for a voltage intermediate between 110 and 6.3 kV, which may be 35 kV. The winding carrying it is called the *medium-voltage* (M.V.) *winding*.

The theoretical feasibility of a transformer having three windings per limb is borne out by all previous reasoning.

Indeed, the magnetic flux set up about the primary (the 110-kV winding in our example) has its path in the core and, so, cuts through the turns of the secondary (L.V.) winding. The terminal voltage of the secondary is 6.3 kV. If to each limb is added one more winding concentrical with the first two windings (Fig. 14), the magnetic flux will cut through the turns of the added winding exactly as the turns of the other two. The terminal voltage of the third (M.V.) winding will be proportional to its number of turns, T_3 (35 kV in our example). In other words, the supply voltage V_1 is simultaneously transformed into two voltages, V_2 and V_3. What we have obtained is a *three-winding transformer.*

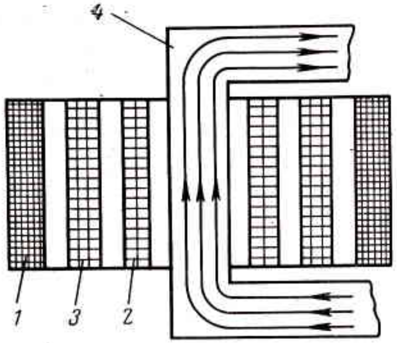


Fig. 14. Arrangement of windings in a three-winding transformer: 1—H.V. winding; 2—L.V. winding; 3—M.V. winding; 4—core

In fact, a three-winding transformer is a combination of two transformers which can operate both together and separately. In both cases, however, the power taken by the primary (20 MVA) should be equal to the sum of the loads on the two secondary windings at all times.

As an example, assume that both the adjacent factory and the remote industrial area can take each 20 MVA. This implies that both the L.V. (6.3-kV) and the M.V. (35-kV) windings should be designed to deliver 20 MVA. Since, however, the transformer can deliver only a total of 20 MVA, either the factory or the industrial area can operate at full capacity at a given time, or they can operate simultaneously, as long as their aggregate power consumption does not exceed 20 MVA.

The operation of each pair of windings of a three-winding transformer (the primary and one of the two secondaries) at no-load or under load and on a short circuit may be represented by the same vector diagrams as the operation of a two-winding transformer (see Figs. 4 and 5). When the three windings are in operation simultaneously, the vector diagram should take into account the fact that the primary current is now the vectorial sum of three currents: the no-load current and two secondary currents.

Three-winding transformers have found a fairly broad field of application. They are more attractive than two-winding units in several respects: initial cost is lower, power losses are smaller and performance is usually better than in the case of two ordinary two-winding transformers of the same kVA rating.

13. *The Autotransformer*

In some cases, use is made of transformers in which a certain portion of the winding is common to both the primary and the secondary circuits.

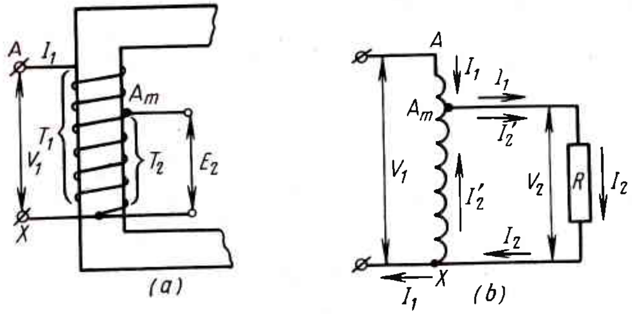


Fig. 15. Operation of an autotransformer: a—at no-load; b—under load

Diagrammatically this is shown in Fig. 15. The core carries a single winding AX of turns T_1. The applied voltage is V_1. The current I_1 produces a magnetic flux and an e.m.f. E_1 which is equal in magnitude (if we neglect the voltage drop across the winding) and opposite in direction to the applied voltage. The e.m.f. per turn is E_1/T_1. The e.m.f. across some portion of the winding, say T_2, will be $E_2 = (E_1/T_1)T_2$.

If a tap be provided at the point A_m, a secondary will be obtained with turns T_2, and e.m.f. E_2, Fig. 15 (*a*). Let the secondary circuit be completed through a load R, Fig. 15 (*b*). A current will flow in the winding A_mX. Since this is an induced current, it will be opposite in direction to the current I_1. The current in the secondary circuit, I_2, as in an ordinary transformer, will vary with the load. This secondary current I_2 is equal to the sum of the primary current I_1 and the current I_2' induced in the secondary winding, or

$$I_2 = I_1 + I_2'$$

The ratio of transformation of an autotransformer is

$$k = \frac{T_1}{T_2} \approx \frac{V_1}{V_2}$$

In the Soviet Union the performance of autotransformers is evaluated in terms of *circuit* power, S. It gives the rating of a conventional (double-wound) transformer which would be required to replace a given autotransformer.

The secondary power of an autotransformer is

$$S_2 = V_2I_2 = V_2(I_1 + I_2') = V_2I_1 + V_2I_2'$$

i.e., it consists of two components: V_2I_1 and V_2I_2'.

The component V_2I_1 is directly transferred conductively to the secondary circuit by the primary current without any transformation owing to the electrical connection between the primary and secondary circuits. Therefore, this component may be termed the *conductive kVA* of an autotransformer, S_{cond}.

The component V_2I_2' is transferred to the secondary circuit by the current I_2', which is the other component of the secondary current. Since this is effected by transformer action, or electromagnetic induction, this component may

be termed the *electromagnetic kVA* of an autotransformer, S_{em}.

The size and weight of any transformer (including the iron and the copper) are mainly determined by the power it has to transform. Therefore, the size and weight of an autotransformer are mainly governed by the electromagnetic kVA it has to transform.

The electromagnetic kVA of an autotransformer is termed its *equivalent kVA parts*. The ratio of the equivalent kVA parts to the circuit kVA is termed the *co-ratio* of an autotransformer:

$$\alpha = \frac{V_2I_2'}{V_1I_1} = \frac{S_{em}}{S}$$

or

$$\frac{V_2I_2'}{V_1I_1} = \frac{V_2(I_2 - I_1)}{V_1I_1} = \frac{1}{k}\left(\frac{I_2}{I_1} - 1\right) = \frac{1}{k}(k-1) = 1 - \frac{1}{k}$$

where k is the ratio of transformation of an autotransformer.

From $S_{em} = \alpha S$, it follows that the equivalent kVA parts and, consequently, the size and weight of an autotransformer decrease with decreasing co-ratio.

The low values of the co-ratio are obtained when the ratio of transformation is very small, approaching unity. Therefore, autotransformers are best suited for applications involving small ratios of transformation. A few examples follow.

Let a power of 50 kVA be transferred from a circuit with a voltage $V_1 = 380$ volts into another circuit with a voltage $V_2 = 230$ volts. If an autotransformer be used for the purpose ($k = 380 : 230 = 1.65$), its co-ratio will be

$$\alpha = 1 - \frac{230}{380} = 1 - 0.6 = 0.4$$

This means that, instead of a 50-kVA double-wound transformer, use may be made of an autotransformer with only $50 \times 0.4 = 20$ kVA parts. Such an autotransformer will take less active material (core steel and winding copper), and its losses in service will also be smaller.

If the same amount of power be transferred from a supply circuit with a voltage $V_1=6{,}300$ volts ($k=6{,}300:230=27.4$), the kVA parts factor will be

$$\alpha = 1-\frac{230}{6{,}300} = 1-0.036 = 0.964$$

This means that the equivalent kVA parts of the autotransformer will be 96.4 per cent of the kVA of an ordinary double-wound transformer, or practically the same. If we add to this that the circuits with different voltages (6.3 kV and 0.23 kV) have a common electrical connection in the autotransformer and, consequently, the insulation of the L.V. winding must be as heavy as that of the H.V. winding, it will become immediately obvious that there is little to be gained by using an autotransformer in this case.

Apart from a number of advantages, autotransformers have several limitations. One of them, already mentioned, is that an electrical connection exists between the primary and the secondary circuits and that the L.V. winding has to be insulated for the full value of high voltage. Another limitation is that the reactance of an autotransformer is normally less than that of the equivalent two-winding transformer and the inherent ability to protect itself from excessive short-circuit currents is much lower. Because of this, large autotransformers have to be equipped with devices which would do this job for them.

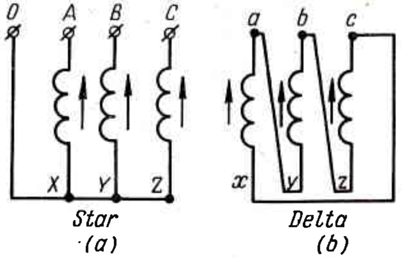
In the Soviet Union, autotransformers are widely employed for interconnecting high-voltage lines with voltages of 110, 154, 220, 330, 400 and 500 kilovolts.

14. Winding Connections and Phase Displacement Groups of Transformers

Under USSR State Standard (ГОСТ) 401-41, the starts and finishes of transformer windings are designated in a specified manner. The starts of the windings of a single-phase transformer are designated by the letters A and a, while the finishes by the letters X and x. The capital letters apply to the H.V. winding, and low-case letters to the L.V. winding. The start and finish of an M.V. winding, if there is any, are designated by the letters A_m and X_m.

The starts and finishes of the windings in three-phase transformers are designated by the letters A, B, C, and X, Y, Z on the H.V. side; by the letters A_m, B_m, C_m and X_m, Y_m, Z_m on the M.V. side; and by the letters a, b, c and x, y, z on the L.V. side.

In three-phase transformers with star-connected windings, the neutral point, i.e., the common point of the three windings, is sometimes made available for connection. It is designated 0, 0_m and 0, respectively.



Star (a)

Delta (b)

Fig. 16. Connections of transformer windings: a—star; b—delta

Fig. 16 (a) and (b) gives the conventional diagrams of transformer windings connected in a star and in a delta. The symbol for the star connection is "Y", and for the delta connection Δ (or D). Where the neutral terminal is provided, the subscript "0" is added to the symbol "Y" (Y_0).

For a transformer with the H.V. winding star-connected and the L.V. winding delta-connected, the designation of the winding connections will be Y/Δ or Y_0/Δ, i.e., the connection symbol of the H.V. winding is the numerator and that of the L.V. winding is the denominator of the "fraction". If a transformer has a M.V. winding, its connection symbol is placed between those of the primary and secondary, or

$$Y_0/Y/\Delta$$

It should be noted that the leads of a winding are designated as a start or a finish in a relative sense, because for alternating current any lead of a winding may be taken as its start. Yet, for practical reasons in the manufacture and, especially, in connection of windings, this convention of lead marking is useful and, indeed, indispensable.

Consider two turns one of which (*1*) belongs to the primary and the other (*2*) to the secondary. Both turns are linked by the same magnetic flux Φ_0, Fig. 17 (*a*). The directions of the induced e.m.f.s (at a given instant) are indicated by the arrows. Let the left-hand terminals be the starts and the right-hand terminals be the finishes of the turns. Then they may be designated A and a, X and x, respectively. With this notation, the e.m.f.s E_1 and E_2 in the turns are said to be in phase, since at any instant they flow in the same direction: either from start (A and a) to finish (X and x), or from finish (X and x) to start (A and a).

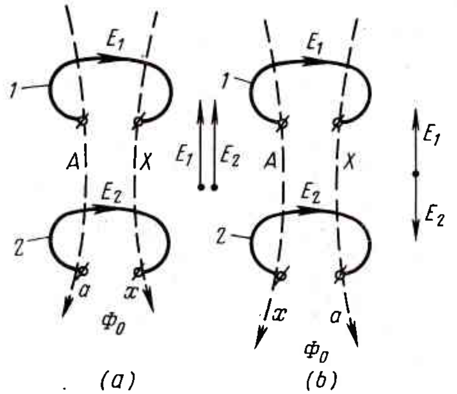


Fig. 17. Phase displacement between e.m.f.s depending on lead polarity:

a—E_1 and E_2 in phase; *b*—E_1 and E_2 reversed in phase; *1*—primary turn; *2*—secondary turn

Now we shall change the polarity of the leads in the secondary, Fig. 17 (*b*). Of course, the e.m.f. will now be induced as before, but its direction with respect to the leads of the turn will be reversed. Since nothing has changed in turn *1*, we must assume that the e.m.f.s E_1 and E_2 are 180° out of phase with each other. In other words, a simple change in the polarity of the leads has amounted to a phase reversal in the winding.

However, the e.m.f.s in the primary and secondary may be in phase opposition even though their starts and finishes are arranged identically. This will be the case when one of the windings is wound clockwise, and the other counterclockwise (the upper and the lower windings in Fig. 18, respectively).

Referring to Fig. 18, the leads of both windings are designated identically. Since the windings are linked by the same magnetic flux, the e.m.f.s in each turn of both windings must be in the same direction. Because of the difference in the winding direction, however, the total e.m.f. of all the series-connected turns in either of the two windings will be different. In the primary, it will be from start A to finish X, and in the secondary from finish x to start a.

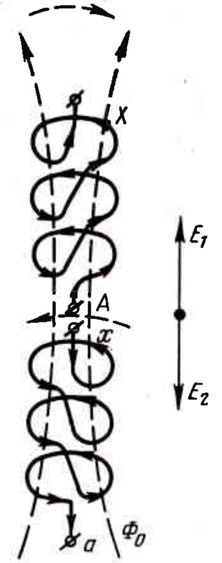


Fig. 18. Phase displacement between e.m.f.s depending on winding direction

In a single-phase transformer the vectors of the e.m.f.s in the windings may be either in the same or in opposite directions, Fig. 19 (*a*) and (*b*). If such a transformer is used alone, the direction of the e.m.f.s in its windings will be immaterial to receivers. If, however, three single-phase units supply the same three-phase line, for proper operation it is essential that the e.m.f.s in all the transformers be as shown either in Fig. 19 (*a*) or in Fig. 19 (*b*).

This observation fully applies to a three-phase transformer. If in the primaries the phase e.m.f.s are all in the same direction, the e.m.f.s in secondaries must also be in the same direction, Fig. 19 (*c*). To meet this requirement, the secondaries must be wound all in the same direction and have the same lead polarity.

If, by mistake, coils wound in different directions are placed on the same core or the leads are connected with wrong polarity, there will be a sharp decrease in the voltage delivered to the load, and normal operation will be upset.

An abnormal condition will also arise if several transformers operating from the same supply circuit have different angular displacements between the line e. m. f. s. To avoid this, only transformers with some certain angular displacement may be operated together (in parallel).

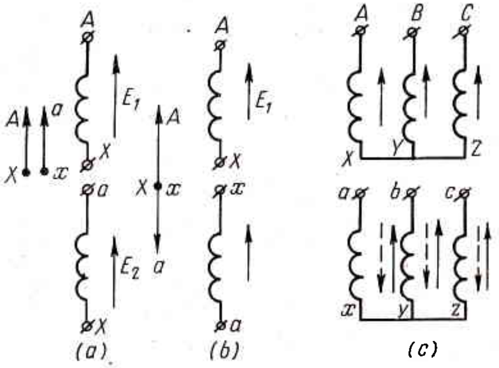


Fig. 19. Direction of e.m.f.s in transformer windings:
a, *b*—single-phase; *c*—three-phase

On the basis of e.m.f. vector direction and angular displacements, transformers may be classed into several groups.

A convention adopted internationally to indicate phase displacement is to use a figure which represents the hour indicated by a clock when the minute hand takes the place of the line e.m.f. vector for the primary side and is set at 12 o'clock and when the hour hand represents the line e.m.f. vector for the secondary side.

When the e.m.f. s in both windings are in the same direction the phase displacement is zero, and a clock figure of 12 will be obtained, Fig. 19 (*a*). Accordingly, this vector group is designated by reference number 12. In the case of 180° phase displacement, Fig. 19 (*b*), a clock-hour figure of 6 is obtained, and the vector group is designated by reference number 6.

As has been shown, single-phase transformers can only have zero and 180° phase displacements. Consequently, they may only have reference number 12 or 6. For brevity, the winding connections of single-phase transformers are designated by the symbols *I*/*I*-12 and *I*/*I*-6.

Three-phase transformers, whose windings may be connected either in a star or in a delta, may be classed into twelve phase-displacement groups with the phase displacement between the vectors of the line e.m.f.s varying from zero to 360° in steps of 30°, which corresponds to twelve clock-hour figures. Out of the twelve possible groups, only two groups are specified by the relevant standard in the Soviet

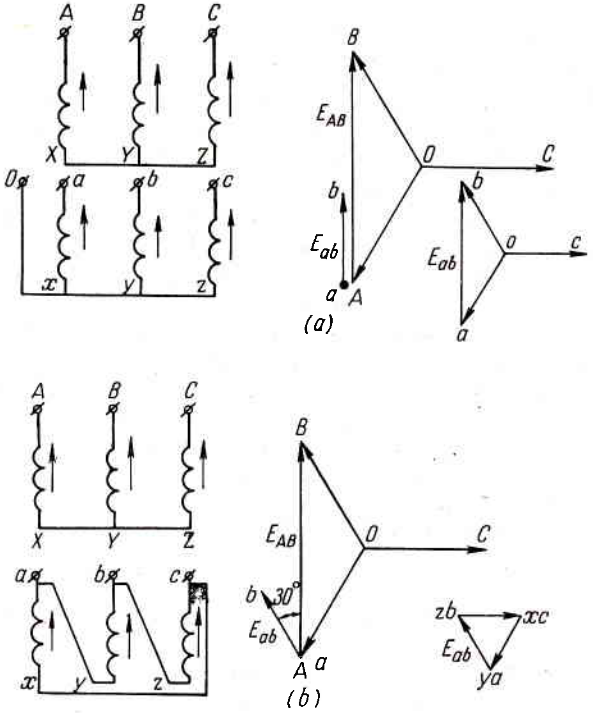


Fig. 20. Identification of winding connections for reference vector group:
a—for star-star connection; *b*—for star-delta connection

Union: group 11 (330°, or minus 30°, phase displacement) and group 12 (zero displacement).

As an example, let us examine the Y/Y and Y/Δ connections of Fig. 20 (*a*) and (*b*). The windings placed on the same limb are shown one above the other. Both the primary and the secondary are assumed to be wound in the same direction. The directions of the phase e.m.f.s are shown by the arrows.

In the vector diagram of the e.m.f.s in the primary, Fig. 20 (*a*), the vector representing the voltage of phase C is drawn horizontally. The vector representing the line e.m.f. E_{AB} (AB) is obtained by connecting the ends of the vectors A and B. It points at 12 o'clock.

Since the e.m.f.s in the primary and the secondary are in the same directions, the vectors representing the phase voltages of the secondary are drawn parallel to those representing the corresponding phase voltages of the primary. The vector representing the line e.m.f. E_{ab} (ab) is drawn by connecting the points a and b. By placing the vector ab representing the e.m.f. E_{ab} at point A, we can see that it also points at 12 o'clock. Thus, the phase displacement between the line e.m.f.s of the primary and the secondary is zero. Consequently, the connection in the first example belongs to phase-displacement group 12, and its vector symbol will be Y/Y-12.

From examination of the example in Fig. 20 (*b*) we note that the vector diagram of the e.m.f.s in the primary is similar to that in the first example. As far as the vector diagram of the secondary e.m.f.s is concerned, it should be remembered that in a delta connection the phase and line e.m.f.s are of the same magnitude and direction.

The vector representing the e.m.f. of phase c is drawn parallel to the vector representing the e.m.f. of phase C in the primary. The finish of phase c (terminal z) is connected to the start of phase b. Therefore, the vector representing the e.m.f. of phase b is drawn from the end of vector c parallel to the vector B. The finish of phase b (terminal y) is connected to the start of the phase a. Therefore the vector representing the e.m.f. of the phase a is drawn from the end of the vector b parallel to the vector A. In the triangle abc thus obtained, the vector ab represents the line e.m.f. E_{ab}. Drawing the vector E_{ab} from the point A, we can see that it makes an angle of 30° with the vector E_{AB}. Thus, the vector E_{ab} points at 11 o'clock, and the connection in the second example belongs to phase-displacement group 11. Its vector symbol will be Y/Δ-11.

In a three-winding transformer, the group of connection is identified in a similar way by considering the windings in pairs: the primary and one of the secondaries in turn.

The vector symbol Y_0/Y/Δ-12-11 refers to a three-winding transformer which has its H.V. winding star-connected with a neutral terminal, provided its M.V. winding also star-connected, and the L.V. winding delta-connected. The clock-hour number for the H.V. and M.V. windings is 12. For the H.V. and L.V. windings it is 11.

15. *The Parallel Operation of Transformers*

Transformers are said to operate in parallel when the like leads of the H.V. and L.V. windings are connected to the like conductors of the line (Fig. 21).

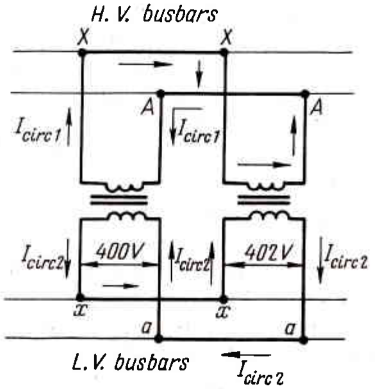


Fig. 21. Parallel operation of two single-phase transformers

The parallel operation of transformers is advantageous from the view-point of convenience and economy. It was stated earlier that the load on transformers does not remain constant, because the power demand of a given user varies within broad limits during a day. Yet, the installed capacity of the transformers should be ample enough to take care of any demand at any time.

A single transformer might be installed of a capacity sufficient to sustain any load. Unfortunately, it would have to be kept continuously energized, although it would operate at full capacity only a small fraction of the time.

We have learned that the no-load losses in a transformer are always present and independent of the load. Whatever the load on a transformer, some of the input power will be wasted as the iron loss. The user would put up himself with these losses, if the transformer operated at full capacity. Under partial load, however, when a transformer delivers only part of its output power to the receiver circuit, the no-load loss makes its operation uneconomical.

For this reason, a single large-capacity transformer is in many cases replaced by two or several transformers of lower capacity. The transformers are connected in parallel both on the H.V. and the L.V. side, but at any given instant only a just sufficient number of transformers is energized. As the load increases, more transformers are put on the line, as the load diminishes, some of the transformers are disconnected from the line. In this way, the number of transformers in operation always corresponds to the load.

Since the no-load loss of several small transformers is always lower than that of an equivalent single transformer, the advantages of operating them in parallel are obvious. In most cases, the additional capital cost of several transformers instead of one is repaid within a short period of time owing to the economy on the iron loss alone.

However, some transformers can be paralleled and some cannot. Transformers will operate satisfactorily in parallel, provided that they have (1) the same ratio of transformation; (2) the same impedance voltage, and (3) the same vector diagram or phase displacement.

(1) Paralleled transformers must have the same ratio of transformation. In other words, their primaries and secondaries, respectively, should be designed for the same voltages. In practical transformers, however, the ratios often differ somewhat. Thus, instead of an exact ratio of transformation equal to, say

$$k = \frac{T_1}{T_2} = \frac{3,000}{400}$$

we have

$$\frac{T_1}{T_2} = \frac{3,000}{402.5} \quad \text{or} \quad = \frac{3,000}{403.2}\text{, etc.}$$

If a transformer operates alone, a difference of two or three volts is immaterial as compared with the required voltage of 400 volts. Trouble may, however, be encountered, if this transformer is to operate in parallel with a transformer whose ratio of transformation is precisely 3,000/400. And the trouble is this. When two transformers have different ratios of transformation, the difference in voltage between the transformers operating in parallel causes a local flow of circulating current in the primary and secondary, entailing a proportional voltage drop across these windings.

Thus, circulating currents decrease the primary and secondary voltages and augment the loss of power, for which reason every effort must be made to prevent them from flowing. Under USSR State Standard (ГОСТ) 401-41, the difference in transformation ratios between the transformers to be paralleled should not exceed ±0.5 per cent.

(2) Paralleled transformers must have the same impedance voltage, E_z. It may be shown that the division of load between paralleled transformers is proportional to their kVA ratings and inversely proportional to their impedance voltages:

$$P = \left(\frac{P_1}{E_{z_1}} + \frac{P_2}{E_{z_2}}\right)E_z$$

where P =common load
P_1 and P_2=kVA ratings of paralleled transformers
E_{z_1} and E_{z_2}=impedance voltages of paralleled transformers

$(P_1/E_{z_1})E_z$
and $(P_2/E_{z_2})E_z$ = kVA delivered by the respective paralleled transformers into the receiver circuit
E_z = impedance voltage of an equivalent single transformer.

An example will show how the value of E_z affects the division of common load.

Let two transformers of 100 kVA each be connected for parallel operation to sustain a common load of 200 kVA. E_{z_1} is 4 per cent and E_{z_2} is 5 per cent. From

$$200=\left(\frac{100}{4}+\frac{100}{5}\right)E_z$$

we get

$$E_z=\frac{200}{25+20}=4.45 \text{ per cent}$$

Then the kVA delivered by each transformer will be:

$$\frac{P_1}{E_{z_1}}E_z=\frac{100}{4}\times 4.45=111 \text{ kVA (approx.)}$$

$$\frac{P_2}{E_{z_2}}E_z=\frac{100}{5}\times 4.45=89 \text{ kVA}$$

As is seen, the transformer with the lower impedance voltage is operating at 11 per cent overload, while the transformer with the greater impedance voltage is underloaded. If the first transformer is not designed for sustained overload, the total load P should be reduced so that the load P_1 be not over 100 kVA. Then

$$\frac{P_1}{E_{z_1}}E_z=100$$

whence

$$E_z=\frac{100\times 4}{100}=4 \text{ per cent}$$

Then

$$P_2=\frac{100}{5}\times 4=80 \text{ kVA}$$

and

$$P=P_1+P_2=100+80=180 \text{ kVA}$$

To sum up, because of the difference in impedance voltage between the paralleled transformers, the total load P has to be reduced by 10 per cent.

Now let $E_{z_1}=E_{z_2}=4$ per cent. Then

$$200=\left(\frac{100}{4}+\frac{100}{4}\right)E_z$$

$$E_z=4 \text{ per cent}$$

whence

$$\frac{P_1}{E_{z_1}}E_z=\frac{100}{4}\times 4=100 \text{ kVA}$$

and

$$\frac{P_2}{E_{z_2}}E_z=\frac{100}{4}\times 4=100 \text{ kVA}$$

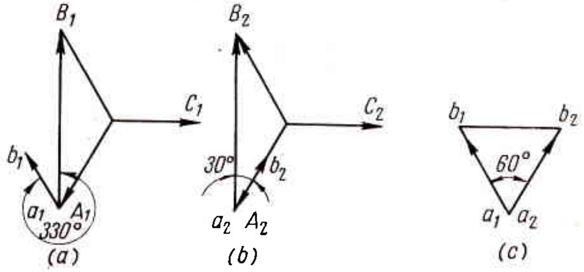
In other words, an equal division of load between paralleled transformers can be accomplished only when they have the same impedance voltage.

According to USSR State Standard 401-41, the impedance voltage should be 5.5 per cent for all transformers with H.V. windings for up to 10 kV inclusive, 6.5 and 8 per cent for up to 38.5 kV inclusive, 10.5 and 11 per cent for 110 kV and higher.

In practical transformers, the actual values of impedance voltage differ from the rated values because of departures from the design dimensions of the windings and core. Therefore, the Standard permits parallel operation of transformers with impedance voltages within ±10 per cent of the rated values.

(3) Paralleled transformers should have the same vector diagram or phase displacement. In other words, in addition to equal voltages on the H.V. side, the paralleled transformers should have the same angular phase displacements between the line voltages both on the H.V. and L.V. side. The example that follows will prove the statement.

Let there be two transformers of references Y/Δ-11 and Y/Δ-1. Fig. 22 (*a*) and (*b*) shows the combined vectors representing the line voltages on the H.V. and L.V. sides of the two transformers. If the primary (high) voltages be equal, then in parallel operation there will be a phase displacement of 60° between the secondary voltages a_1b_1 and a_2b_2, Fig. 22 (*c*), and a vectorial difference of voltages a_1b_1 and a_2b_2 shown by b_1b_2 in the figure. Since the triangle $a_1b_1b_2$ is equilateral, $b_1b_2=a_1b_1=a_2b_2$, i.e., equal to the line voltage on the L.V. side.



(*a*) (*b*) (*c*)

Fig. 22. Determination of voltage between the L.V. windings of paralleled transformers of different reference vector groups: *a*—group reference Y/D-11; *b*—group reference Y/D-1; *c*—vector diagram of paralleled transformers of phase-displacement groups 11 and 1

To sum up, there will be a difference of voltage between the L.V. windings of the paralleled transformers, equal to the line voltage on the L.V. side. As a result, circulating currents will flow in both the L.V. and H.V. windings. This is a proof that transformers with different phase displacements cannot be paralleled.

16. Heating and Cooling of the Transformer

The electrical energy lost in a transformer in operation is dissipated as heat in the windings, the core, the structural and other parts of the transformer. As a result, the transformer is heated up, and some of its parts may exceed the maximum safe temperature.

The metallic parts of a transformer can endure elevated temperatures without damage for a fairly long time, while the insulation, especially the insulation of the winding conductors, cannot.

It has been established that paper insulation, which is the principal insulation in present-day oil-immersed transformers, retains its electric strength as long as its mechanical strength is not impaired. However, both time and temperature have the effect of decreasing the mechanical strength of paper insulation which gradually becomes brittle and mechanically weak. This process, known as *aging*, goes on at a rate which increases with increasing temperature of the windings.

Severely aged insulation becomes so brittle and weak that the vibration and mechanical stresses existing in any transformer cause it to disintegrate. Electrical failure of the transformer will finally result from this physical disintegration.

The time over which the insulation deteriorates so much that it becomes unfit for use depends on its temperature. All other factors being equal, the service life of transformers decreases with increasing temperature.

In the Soviet Union, the maximum safe temperature of transformer insulation is such as would ensure the transformer a service life of 20 to 25 years. Experimentally it has been established that for paper insulation immersed in oil the maximum safe temperature (i.e., a temperature at which the insulation does not lose much of its insulating properties) is 105°C.

Accordingly, USSR State Standard 401-41 specifies that for transformers intended for use in localities where the ambient temperature does not exceed +35°C the average temperature rise of the windings over ambient (as measured by resistance) shall not exceed

$$105° - 35° = 70°\text{C}$$

However, the ambient temperature varies over a day and over a year, as does the load. Consequently, the temperature of the windings (and of the insulation) will never be equal to 105°C. Experience and tests indicate that if the average temperature of the windings (as measured by resistance) be maintained by some means at 105° all the time, the service life of the transformer would hardly exceed two years. Therefore, the 105° figure should be understood as the maximum safe temperature (as measured by resistance) during a few hours a day on the few days when the ambient temperature reaches 35°C which gives a satisfactory service life of the transformer.

As stated earlier, the windings, core and various structural parts of a transformer in operation are heated, for which reason they are constant sources of heat. Therefore, there is a continuous transfer of heat in the core and windings from the hotter to the cooler parts which give up the heat to the surroundings. On this account, transformers are so built as to make the surface area of the cooler parts sufficiently large for efficient heat transfer.

In transformers with a capacity of a few kilovolt-amperes, the cooling surface of the windings and core is sufficiently large to abstract what heat may be liberated in them in operation. Such small-capacity transformers are cooled by the cooler ambient air through natural radiation. There are no special facilities for cooling. Such transformers are called *self-air-cooled* or, simply *air-cooled*. Since they use ony solid insulation built into their structure, they are also referred to as the *dry type*.

As transformer capacity increases, the losses also increase, and they do so in proportion to the weight of transformers, i. e., as the cube of their linear dimensions. At the same time, the area of the cooling surfaces increases as the square of their linear dimensions. To state this differently, the losses in transformers increase at a faster rate than the area of the cooling surfaces..

At a certain definite capacity, the area of the cooling surfaces becomes insufficient, and ducts have to be provided between the coils so as to increase the area exposed to cooling air. However, this device suffices only for transformers with a capacity of 630 to 1,000 kilovolt-amperes. Large transformers have to be equipped with air blowers for a forced circulation of air through the core and windings so as to improve heat abstraction. Such transformers are termed as *air-blast-cooled*.

Still better cooling is provided by the use of transformer oil. The transformer is immersed in a steel tank filled with oil. Such transformers are called *oil-immersed* or *oil-cooled*. The oil next to the coils and core is increased in temperature which decreases its density. The lighter oil rises and is replaced by the cooler and, consequently, the heavier oil from below. On rising to the surface, the hotter oil comes in contact with the walls and cover of the tank and transfers its heat to them. The heat is then dissipated into the surrounding air by radiation. The cooled oil goes down to be replaced by the hotter oil. Thereby a continuous circulation of oil which transfers heat from the hot parts of the transformer to the cooler tank walls is set up.

Naturally, the temperature of the oil in the tank is not the same at the bottom as at the top. It is lowest at the bottom and highest at the top, being an average somewhere at the middle of the tank. According to USSR State Standard 401-41, the temperature rise of the oil at the top of the tank (or, simply, the *top oil*) over ambient should not exceed 60°C. The top oil rise can be determined by subtracting the ambient temperature at the instant of measurement from the temperature of the top oil (as measured by thermometer). If, for example, the temperature of the top oil (by thermometer) is 80°C and the ambient temperature is 25°C, the top oil rise will be 80°—25°=55°C, which is below the safe limit.

Transformer oil is an extremely efficient heat-transfer medium. Experiments have shown that in the case of oil cooling heat transfer per unit area is six to eight times greater than with air cooling. This implies that the windings and core of an oil-immersed transformer may have a much smaller area than those of an equivalent dry-type air-cooled transformer.

However, the surface of the tank which dissipates heat into the surrounding air should be made sufficiently large; if it is not, the oil temperature will exceed the safe limit. The simplest way to do so is to increase the linear dimensions (length, width and depth) of the tank. However, this method is uneconomical, since it leads to an increase in the overall dimensions of transformers. A better way is to use corrugated tank walls, tanks with external welded-on tubes (tubular tanks), or separate tubular coolers (radiators).

With any of the above arrangements, transformers are termed *oil-natural-cooled* or *oil-immersed self-cooled*. This system of cooling is quite efficient for transformers of up to 6,300 kilovolt-amperes in capacity. On larger capacities, the oil has to be cooled by artificial means.

The three methods of artificial oil cooling widely employed in Soviet-built transformers are: *oil-natural air-blast cooling*, *forced-oil and water cooling*, *forced-oil air-blast cooling*.

In the case of oil-natural air-blast cooling, an air blast from an air blower is applied to either an ordinary tubular tank or a tubular radiator. Such transformers are also known as *oil-immersed forced-air-cooled*.

In the case of forced-oil and water cooling, the hot top oil is forced by pumps through a water cooler, and the cooled oil is returned to the tank. Such transformers are also termed *oil-immersed forced-oil-cooled*.

In the case of forced-oil air-blast cooling, the oil is forced by pumps through radiators on which an air blast is applied by air blowers.

Chapter

2 Design Features of Low- and Medium-capacity Transformers

17. *Classification, Designations and Performance*

USSR State Standard (ГОСТ) 401-41 classifies all power transformers built in the Soviet Union into five groups or sizes according to their voltage and capacity as follows:

Size 1: transformers with a capacity of 5 to 10 kilovolt-amperes, inclusive;

Size 2: transformers with a capacity of 180 to 560 kilovolt-amperes, inclusive;

Size 3: transformers with a capacity of 750 to 5,600 kilovolt-amperes, inclusive;

Size 4: transformers with a capacity of 7,500 kilovolt-amperes and higher with a voltage of 35 kilovolts, and also all other transformers with a voltage of 110 kilovolts on the H.V. side;

Size 5: transformers with a capacity of 40,000 kilovolt-amperes and higher with a voltage of 220 kilovolts and higher on the H.V. side.

In this book we shall deal only with transformers of Size 1 through 3, with a capacity of up to 5,600 kilovolt-amperes and a voltage of not over 35 kilovolts on the H.V. side.*

Transformer types are designated by letters and numerals as follows:

The number of phases is given by the letter O for single-phase, and by the letter T for three-phase units.

The system of cooling is designated by the letter M for oil-natural cooling, by the letter Д for oil-natural air-blast cooling, by the letter Ц for forced-oil and water cooling,

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[*] USSR State Standard 9860-61 has introduced a new classification of transformers by capacity. Under this standard, Size 1 through 3 include transformers with a capacity of 10 to 6,300 kilovolt-amperes and an H.V. voltage of not over 35 kilovolts.

by the letters ДЦ for forced-oil air-blast cooling, and by the letter C for air cooling.

The number of windings is given by the letter T (other than placed at the beginning of a type designation) for three-winding units (two-winding transformers have no special designation).

Special features and application are designated by the letter H for on-load tap changing, by the letter Г for lightning protection, by the letter Ш for mine service, by the letter P for application in conjunction with mercury-arc rectifiers, the letter Э for application with arc furnaces, the letter Б for use in drilling rigs, the letter И for testing transformers, etc.

The letter designation is followed by a fractional number with the numerator giving the kVA rating of the transformer and the denominator indicating its kV on the H.V. side.

For example, the type designation "TM 100/6" should be read as follows: a three-phase (T), oil-natural-cooled (M) transformer with a capacity of 100 kilovolt-amperes and an H.V. voltage of 6 kilovolts. The designation "TMTБ 560/10" reads: a three-phase (T), oil-natural-cooled (M), three-winding (T) transformer for application in drilling rigs (Б) with a capacity of 560 kilovolt-amperes and an H.V. voltage of 10 kilovolts. The designation "ТЦТНГ 63,000/220" refers to a three-phase (T), forced-oil and water-cooled (Ц), three-winding (T), on-load tap-changing (H), lightning-protected (Г) transformer with a capacity of 63,000 kilovolt-amperes and an H.V. voltage of 220 kilovolts.

There is an additional letter A in the type designations of autotransformers.

18. General Design of Transformers

The key elements of a transformer are the *core* and the *coil* (or *windings*). We have already learned that the core is the magnetic circuit of a transformer, through which a magnetic flux circulates, while the coils constitute its electric circuits in which the primary and secondary currents flow.

The core and coils are put together into a single *core-coil* assembly which can be handled separately as a complete unit.

It is frequently desirable on transformers to obtain a voltage which is slightly different from its rated voltage. This is mostly done by varying the number of active turns in the H.V. winding. In most transformers of Size 1 through 3 this is done with the transformer disconnected from the line, i.e., de-energized or off-load, by means of a special *tapping switch*, also called the *ratio adjuster* or *off-circuit tap changer*. Provisions may be made for on-load voltage control or tap changing. This is effected by suitable on-load tap-changing equipment which consists of several components.

Connections between the coils, to the ratio adjuster and to the terminal bushings on the tank cover are made by means of *leads*.

Connection of the transformer windings to the external circuits is through *bushings* consisting each of a central conductor (of rod or tubular construction), a porcelain insulator (the bushing proper), and a mounting flange. Bushings are mounted either on the cover or the wall of the transformer tank so that their lower ends, or shanks, are immersed in oil inside the tank and the upper ends are surrounded by air outside the tank.

The core-coil assembly together with the leads and tapping switch is placed in the *tank* which consists of a shell, bottom and cover and serves as a container for oil. The tank may have cooling tubes welded to it or detachable tubular radiators. The cover carries all the accessories and fittings of the transformer. Attached to the bottom is a *truck* on which the transformer can be moved about within the substation at slow speed.

When a transformer is energized, its parts (the coils, leads, tapping switch, etc.) are at high potential with respect to the core, tank and other earthed parts, and also with respect to each other. This is why reliable insulation should be provided between them.

The insulating materials used in transformers may be solids and liquids. Solid insulations most commonly used in transformers are electrical pressboard, paper, wood, paper-base laminates, etc. Liquid insulations include mineral (transformer) oil which serves both as an insulation and as a cooling medium.

In a core-type magnetic circuit, Fig. 24 (*a*), the vertical limbs *1* are of multi-step cruciform section approaching a circle. The limbs carry cylindrical windings *3*. The cross members of the magnetic circuit, which do not carry windings but serve to complete the circuit, are called the *yokes 2*.

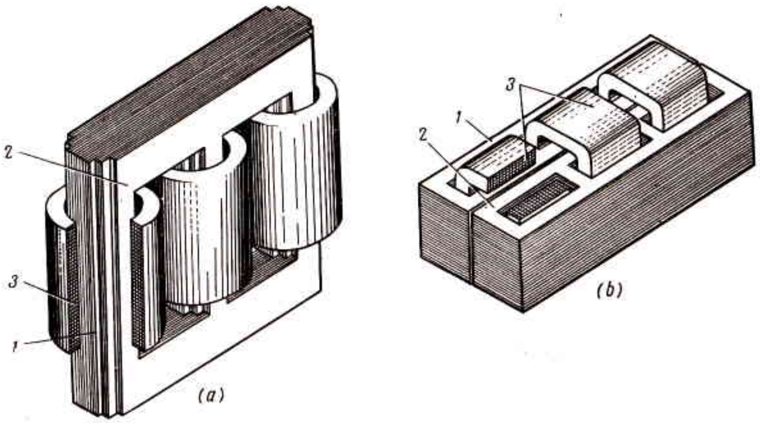


Fig. 24. Forms of transformer magnetic circuits:
a—core type; *b*—shell type; *1*—limb; *2*—yoke; *3*—windings

In a shell-type magnetic circuit, Fig. 24 (*b*), the limbs are placed horizontally and are rectangular in cross section. Accordingly, the windings for shell-type transformers are rectangular. Because of complications in manufacture, the shell type in the Soviet Union is employed only for several special types of transformers. All power transformers are of the core type.

The joints between the limbs and the yokes may be either of the *butt* or of the *interleaved* type.

In the case of butt construction, the limbs and the yokes are stacked up separately, the coils are put on the limbs, and the top yoke is then placed on (joined with) the limbs. The abutting surfaces of the limbs and yokes are separated by pressboard to prevent short-circuiting of laminations. After the top yoke has been mounted, the whole of the magnetic circuit is compressed and clamped by vertical *tie-rods*.

The butt type of core construction greatly simplifies the assembly of a transformer, because the coils can be conveniently mounted on the respective limbs after the top yoke has been removed. Yet, it is never used in power transformers, since it involves the use of cumbersome clamping devices and the machining of the abutting surfaces on the limbs and yokes (which is essential in order to reduce the reluctance at the joints). It is only used in a limited number of special reactor types (Fig. 25) which lie outside the scope of this book.

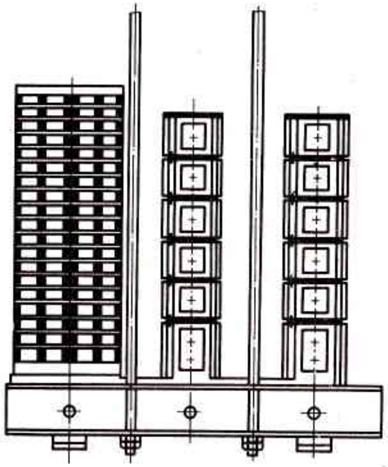


Fig. 25. Butt type of a reactor core

With the interleaved construction, the limbs and the yokes are divided into packets. In each packet the laminations are so stacked that some laminations in a limb interleave with some laminations in a yoke. The laminations in every next packet are made to overlap the joints between the laminations in the previous packet.

The advantages of the interleaved type of core construction are smaller weight, greater mechanical strength, small gaps at the joints, and a low value of exciting current.

On the other hand, interleaved cores considerably complicate the assembly of a transformer: before the coils can

The core-type magnetic circuit is rigidly confined by heavy steel yoke clamps *1* and *8* (Fig. 28) applied on either side of the yokes *4* and *5* and clamped by yoke studs *6*. These studs should be reliably insulated from the yokes to avoid short circuits between the laminations with accompanying increased eddy-current losses, local heating and burns in the iron.

The studs are usually insulated by synthetic-resin-bonded paper tubes *3* (Fig. 29) which are slipped over the studs *2*. The nuts *7* of the yoke studs are insulated from the yoke clamps by paper-base laminate washers *5*. The top yoke clamp *8* also serves for lifting the core-coil assembly and carries lead cleats. The bottom yoke clamp also supports the coil stacks.

Some of the Size 3 transformers have steel *pressure* or *end rings*. Where such rings are used, the top yoke clamp is fitted with adjustable *jack bolts 5* (Fig. 30). In most cases, however, transformers of Size 1 through 3 use tie-rods *7* (Fig. 28) which brace the coil stacks in place to maintain axial alignment under short-circuit conditions. By tightening the nuts on the tie-rods, the top yoke clamps can be pulled down a short distance, thereby taking up any axial shrinkage in the coils that may take place in service.

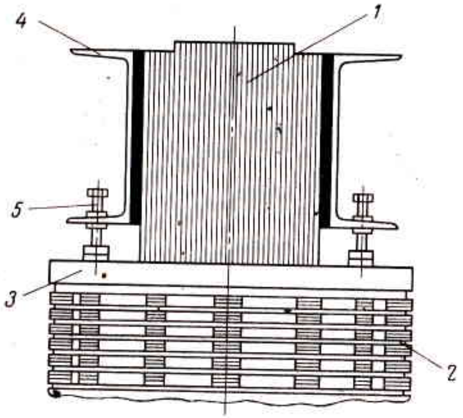


Fig. 30. Clamping arrangement of windings:

1—top yoke; *2*—winding; *3*—steel pressure or end ring; *4*—yoke clamp; *5*—jack bolt

So that the top yoke clamps can be pulled down without moving the yoke studs, the stud holes are made oval or of oversize diameter.

When a transformer is energized, an electric field is set up between the coils and earthed parts (say, the tank). All metal parts within this field will be charged to a certain potential, and there will be differences of potential between the charged parts and the earthed tank.

Although small in magnitude, these potential differences may prove great enough to break down the small air gaps (clearances) between the metal parts. This is an unwanted feature in transformer operation, because breakdowns decompose and spoil the oil and are accompanied by a crackling sound which may be misinterpreted as a sign of trouble in the transformer insulation. To remove electrostatic charges from the metal parts, they are earthed, i.e., kept at earth (tank) potential.

Earthing should be applied to the yoke clamps, all metal brackets and other clamping devices except the yoke studs which are always at a potential very near to that of the core.

Earthing connections are made by copper ribbons inserted between the core laminations at one end and fastened on the yoke clamp at the other. Earthing connections between the top and bottom yoke clamps are by means of the tie-rods, and to the earthed tank by the *lifting rod 10*.

Various earthing arrangements are possible, as they are determined by the core design, fixation of the core-coil assembly in the tank and by the relative position of the individual parts. Whatever the earthing arrangement, it must provide for reliable earthing of all transformer components.

20. The Windings and Insulation

The windings for Size 1 through 3 transformers are wound with round-wire or strip conductors made of copper or aluminium. Round wire is usually enamel- or paper-insulated, while strip conductors are wrapped with several layers of cable or telephone-cable paper.

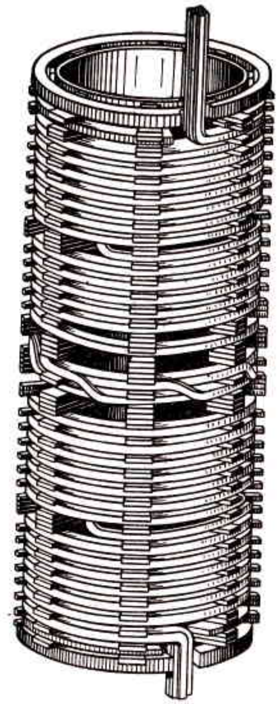


Fig. 34. Spiral winding with several conductors in parallel per turn

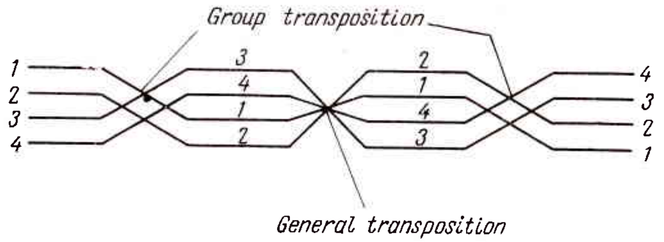


Fig. 35. Transpositions in a spiral winding wound with four conductors in parallel:

1, 2, 3, 4 — conductors

heavy currents. It is strong mechanically and is widely used in transformers as L.V. coils.

The type most commonly used in Size 3 transformers is the *continuous-disk winding* (Fig. 37). It consists of several disks radially wound with strip conductors so that there may be several turns in each disk. Fig. 38 shows part of a disk with two turns wound with two parallel conductors

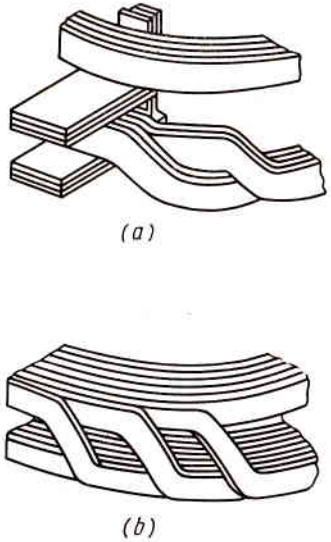


Fig. 36. Transposition of conductors in spiral windings:

a—group transposition; *b*—general transposition

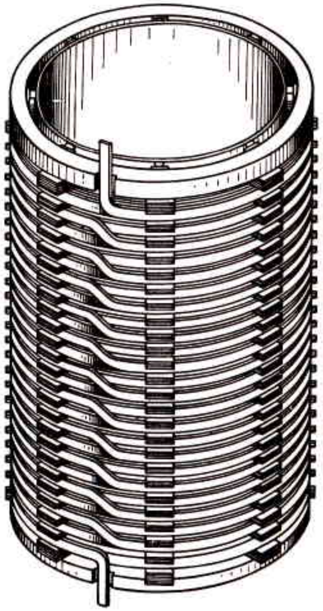


Fig. 37. Continuous-disk winding

This type has been termed "continuous-disk", because the winding is wound with a continuous conductor without a single soldered or welded joint. For continuous interdisk connections, every alternate disk is wound with its turns reversed, while the other disks are wound in the normal manner, so that the interdisk connections are always at the

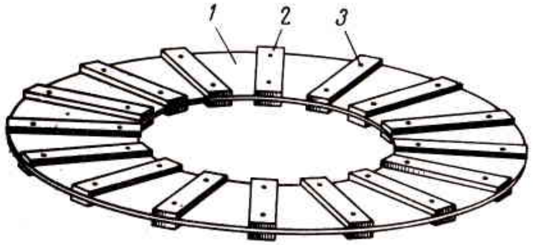


Fig. 40. Yoke insulation:
1—washer; 2—spacing block; 3—rivet

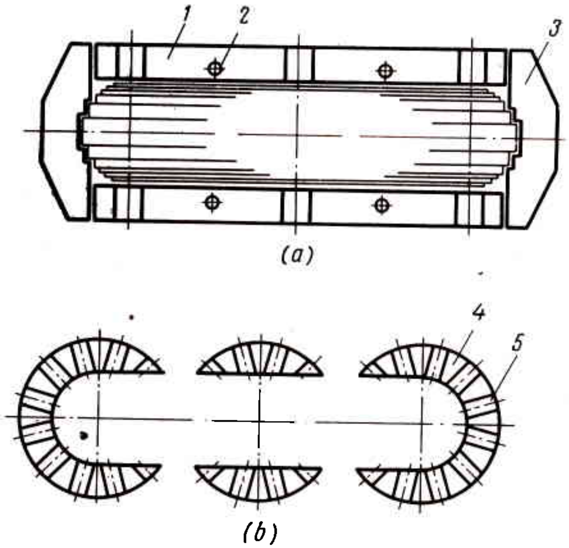


Fig. 41. Coil-end insulation in Size 1 through 3 transformers:
a—wood; b—pressboard; 1—longitudinal block; 2—hole; 3—transverse block; 4—collar; 5—spacer

winding. For this purpose, voltage-control taps are provided on the respective winding.

Fig. 12. shows the off-load (or off-circuit) tap-changing arrangements most commonly used on transformers. These arrangements usually give ±5 per cent variation of the rated voltage. In 100 to 1,000-kVA transformers, usually three taps are provided: 5 per cent above, normal, 5 per cent below, Fig. 12 (*a*), (*c*) and (*e*). Bigger transformers (1,600 to 6,300 kilovolt-amperes) have five taps: 5 per cent above, 2.5 per cent above, normal, 2.5 per cent below, 5 per cent below, Fig. 12 (*b*) and (*d*). In two-winding transformers, voltage taps are placed on the H.V. winding, while in three-winding transformers on the H.V. and M.V. windings. Voltage taps are changed by hand-operated off-load tapping switches, also known as ratio adjusters or tap changers. The tapping switch may be mounted either on the tank cover or on the core-coil assembly. Whatever the type of tapping switch, it consists essentially of a system of fixed contacts (or terminal studs) at which the respective tappings are terminated, and a system of movable contacts (or shoes) which bridge two terminal studs at a time.

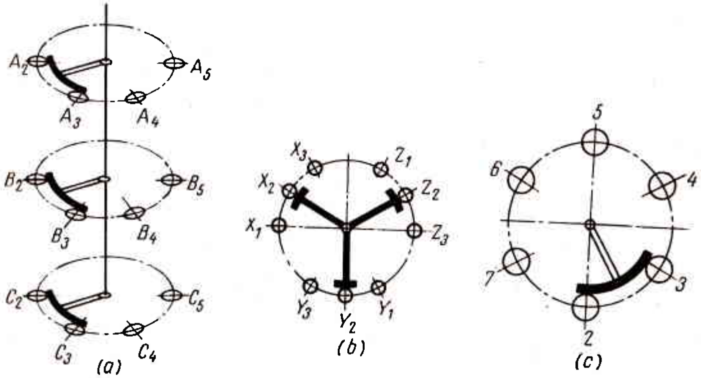


Fig. 42. Arrangement of contacts in tapping switches:
a—three-phase ganged; *b*—three-phase neutral-point; *c*—single-phase

Fig. 42 shows three arrangements of connections in tapping switches. The one at *a* is a three-phase tapping switch applicable to the tap arrangement shown in Fig. 12 (*c*).

At *b* is a three-phase tapping switch for taps placed at the end or in the middle of the winding, Fig. 12 (*a*) and (*b*), respectively. Such switches are sometimes termed *neutral-point switches*, because their shoes bridge the like tappings on different windings, thereby providing a common neutral point. The star connection is obtained in the switch itself. With the tap arrangement of Fig. 12 (*e*), the switch bridges taps x_2, y_2, and z_2, giving the rated voltage of the transformer. Fig. 42 (*c*) shows a single-phase tapping switch applicable to the tap arrangement of Fig. 12 (*d*) and also where a three-phase switch cannot be used because of the heavy current in the windings.

The bridging shoes are shifted by rotating the operating handle or knob located on the tank cover.

A brief description of the most commonly used tapping switches follows.

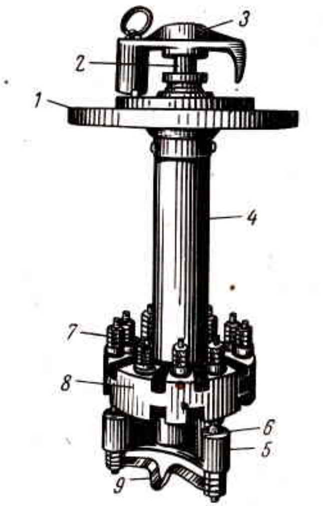


Fig. 43. Type 3-50/35 three-phase tapping switch:

1—switch dial; *2*—steel shaft; *3*—handle; *4*—synthetic-resin-bonded paper tube; *5*—holder; *6*—movable contact shoe; *7*—terminal stud; *8*—plastic disk; *9*—copper ribbon

Type 3-50/35 Switch. Fig. 43 gives a general view of the Type 3-50/35 tapping switch used in transformers up to 1,000 kilovolt-amperes in size for voltages up to 35 kilovolts. The connections are arranged as shown in Fig. 42 (*b*). As any tapping switch, the Type 3-50/35 consists of an operating mechanism and a system of contacts coupled by a synthetic-resin-bonded paper tube.

The switch is mounted so that its top portion is above the tank cover. Through the switch dial *1* passes a steel shaft *2* the top end of which carries the operating handle *3* (Fig. 43). The shaft is placed inside the synthetic-resin-bonded paper tube *4* and is coupled to a rotary holder *5*.

The rotary holder carries three contact shoes *6* which move together with the holder. Under the action of coil springs the contact shoes can also move 3 or 4 mm axially. The springs hold the shoes to the terminal studs *7*. The terminal studs (of which there are nine) are fastened in holes in a plastic disk *8*.

The top ends of the terminal studs receive the taps from the windings, while the bottom ends come in contact with the shoes which are interconnected by a copper ribbon *9*.

The desired position of the switch is obtained by turning the operating handle *3* through 30°. In each position the switch is locked by a suitable stop.

Type ТПСУ-9-120/10 Switch. Transformers with a capacity from 100 to 1,000 kilovolt-amperes at up to 10 kilovolts use the Type ТПСУ-9-120/10 three-phase tapping switch rated for a current of 120 amperes, Fig. 44 (*a*).

The steel operating shaft *17* passes through a flange *4* and is coupled to the operating knob *1* at the top and to a synthetic-resin-bonded paper tube *10* at the bottom. The lower end of the tube carries a crank *11* and brass contact shoes *12*. The lower end of the crank is centred in a paper-base laminate plate *16*. The crankshaft and the contact shoes are enclosed in a synthetic-resin-bonded paper cylinder *8* which is fastened by bolts *7* on a cast-iron flange *9*.

The nine fixed terminal contacts *15*, made of brass, are equidistantly placed at the lower end of the cylinder and have the shape of half-cylinders, Fig. 44 (*b*). The voltage taps are terminated each at one of the fixed contacts on the outside. As they move inside the switch, the contact shoes bridge three fixed contacts at a time. To change taps, the set bolt *3* must be undone and the operating knob turned through 120°.

Type ПТЛ-4-120/35 Switch. This is a gang-operated three-phase switch (Fig. 45) intended for transformers in sizes from 1,600 to 6,300 kilovolt-amperes. The switch is rated for a current of 120 amperes at 35 kilovolts and is applicable to the mid-winding arrangement of taps as shown in Fig. 12 (*c*). It has three contact systems placed one above the other. The fixed contacts *17* are of knife-blade construction and project into the switch housing.

The base of the switch is a synthetic-resin-bonded paper cylinder *16* fastened to flanges *2* and *20* at top and bottom.

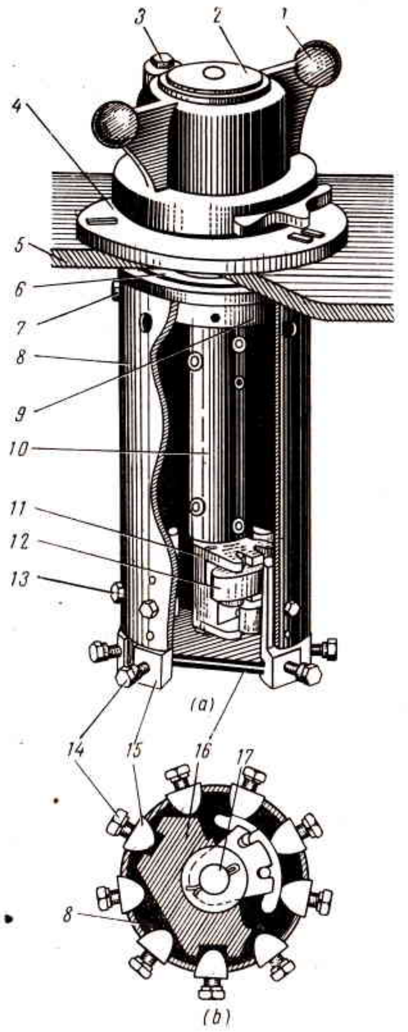


Fig. 44. Type ТПСУ-9-120/10 three-phase tapping switch:

a—general view; *b*—bottom view; *1*—operating knob; *2*—endplate; *3*—set bolt; *4*—flange; *5*—transformer cover; *6*—rubber gasket; *7* and *13*—fastening bolts; *8*—synthetic-resin-bonded paper cylinder; *9*—cylinder flange; *10*—synthetic-resin-bonded paper tube; *11*—crank; *12*—contact shoe; *14*—contact bolt; *15*—terminal contact; *16*—locating disk of paper-base laminate; *17*—operating shaft

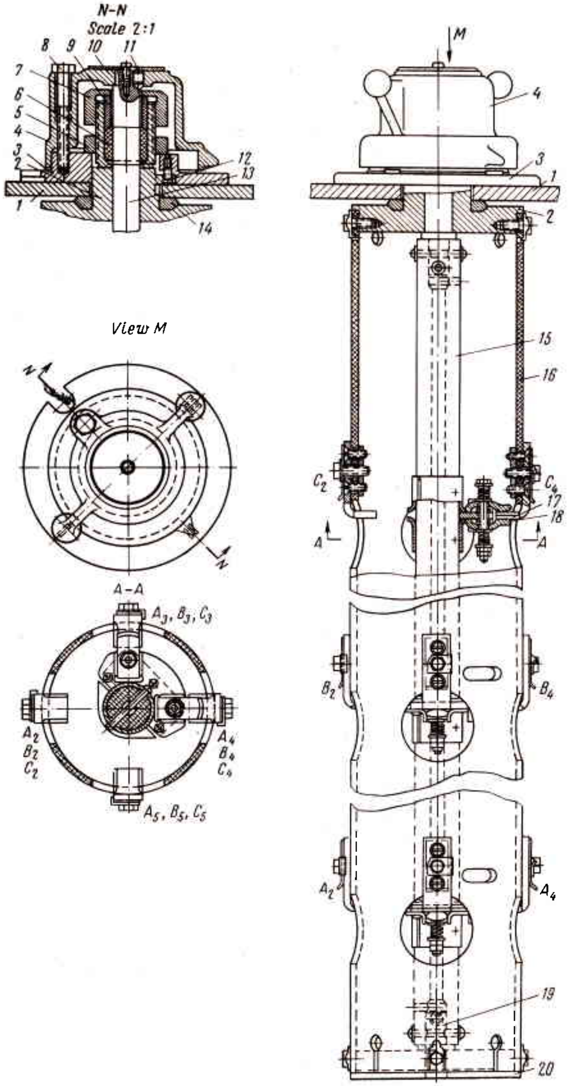


Fig. 45. Type ПТЛ-4-120/35 three-phase tapping switch:

1—tank cover; *2*—top flange of insulating cylinder; *3*—operating-knob flange; *4*—operating knob; *5*—nut; *6*—stuffing; *7*—gland; *8*—set bolt; *9* and *14*—gaskets; *10*—endplate; *11*—stud; *12*—key; *13*—operating shaft; *15*—synthetic-rein-bonded paper tube; *16*—synthetic-resin-bonded paper cylinder; *17*—fixed contacts; *18*—movable contacts; *19*—bottom shaft end; *20*—bottom flange of insulating cylinder

The steel operating shaft *13* runs the whole length of the switch as far as the bottom flange. The shaft carries a synthetic-resin-bonded paper tube *15* on which are mounted movable contact jaws *18*. The tapping connections are terminated at the fixed knife-blade contacts *17* on the outside of the switch. The contact connections are arranged as shown in Fig. 42 (*a*).

For tap changing, the set bolt *8* should be undone and removed from the flange *3*, the operating knob *4* turned through 90° in the requisite direction, and the set bolt again screwed in.

Drum-type Tapping Switches. Transformers of Size 3 and bigger use single-phase drum-type tap changers (Fig. 46). This type of switch consists of two paper-base laminate disks *2* into which are inserted rods (or tubes) *4* which operate as fixed contacts. The movable contacts are rings *5* spring-mounted on a shaft *3*.

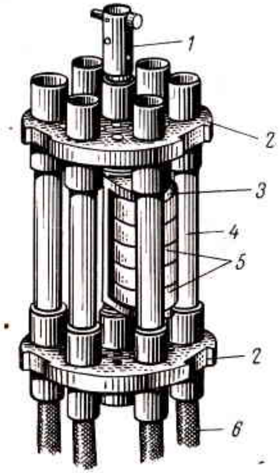


Fig. 46. Drum-type single-phase tapping switch:

1—coupler between operating rod and contact shafts; *2*—paper-base laminate disks; *3*—contact shaft; *4*—contact rod (tube); *5*—contact rings; *6*—cable

Connections between the rods and the voltage taps on the winding are by means of flexible conductors (stranded cables). One end of a flexible conductor is soldered to the respective tap, while the other end is either soldered directly to the corresponding rod or to a terminal screw which is then screwed into the rod.

The drum-type switch is mounted only on the core-coil assembly (Fig. 47) and always in a vertical position. The switch is placed inside synthetic-resin-bonded paper cylinders *9*, *10* and *15* which are mounted on wooden supporting strips *7* and *8*.

The switch is operated by means of a hand knob mounted on a flange *2* on the tank cover. The knob shaft is coupled to the operating rod *5* which is in turn coupled to the contact shaft. Thus, rotation of the hand knob *1* actuates the contact shaft, and the ring contacts move, bridging two rod contacts at a time. The contacts are connected as shown in Fig. 42 (*c*).

22. The Leads

Leads are various conductors located outside the windings and connecting the windings or their coils with each other and also the windings to the terminal bushings and the voltage taps to the terminal studs of the tapping switch. The type and arrangement of leads varies with winding arrangements. The lead system also includes lead supports.

In transformers of Size 1 through 3 leads are assembled with copper and aluminium round conductors, copper and aluminium square bars, and stranded cables.

Bare round conductors (copper or aluminium) are used on voltages up to 525 volts, while on voltages from 6 to 35 kilovolts, use is made of conductors in paper insulation. Paper-insulated conductors are employed for leads with a diameter of up to 5.2 mm. The larger leads either have no insulation at all, or synthetic-resin-bonded paper tubes are slipped on them. Where uninsulated leads are used on voltages from 6 to 3 kilovolts, they should be spaced at a considerable distance from the earthed parts of the transformer. The spacing may be markedly reduced where heavy insulation is applied.

Round conductors are the cheapest; if of not too large a cross section, they can be easily bent to any shape; they

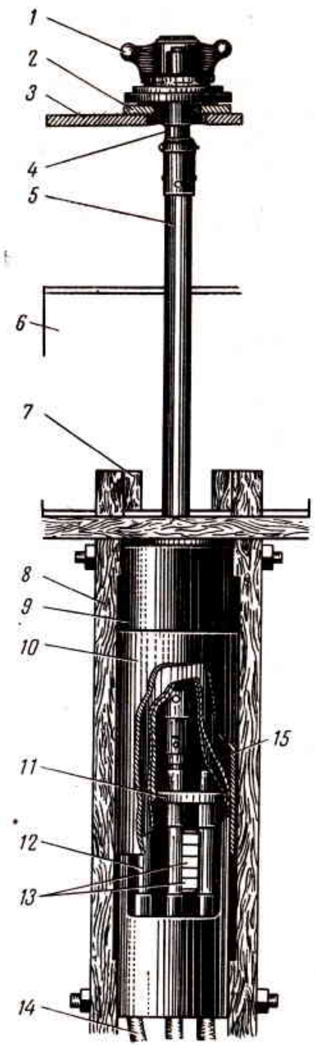


Fig. 47. Installation of a drum-type tapping switch on the core-coil assembly of a transformer:

1—operating knob; *2*—flange welded to tank cover; *3*—tank cover; *4*—operating (knob) shaft; *5*—operating rod; *6*—yoke clamp; *7*—wooden block; *8*—wooden block; *9*, *10*, *15*—synthetic-resin-bonded paper cylinders; *11*—paper-base laminate disk; *12*—contact rod; *13*—contact rings; *14*—cable

can be readily insulated. With large sizes of round conductors, the manufacture of leads is complicated.

Bare rectangular bus bars (copper and aluminium) are best suited for leads over 80 to 100 sq mm in cross section. In transformers, they are mainly used as L.V. leads. Owing to rectangular section, the cooling surface is larger than that of round conductors of equivalent cross-sectional area, so heavier currents may be passed through bus bars.

Flexible cords, consisting of several fine wires 0.57 mm in diameter braided together, are often employed for 35-kV leads. Grade БОТВ flexible cords are usually insulated with paper 3, 6 or 8 mm thick on the side. Flexible cords are easy to bend to any shape.

Copper leads are electric-brazed, using a hard (phosphor-copper) solder. The conductors to be brazed are lap-jointed and clamped between the jaws of an electric-brazing tool, and electric current is passed through the jaws and joint. The current heats the joint and melts the solder which fills all voids in the joint. On cooling, a reliable joint is produced. Aluminium leads are electric-welded in an argon atmosphere which ensures a reliable contact between the conductors.

Bolted joints on leads are used only in a few cases, for example to join leads to terminal bushings. Examples of bolted joints are shown in Fig. 48 (*a*) and (*b*). The bus bar or the flexible cord of the lead is soldered to a flexible connector assembled of light-gauge copper sheets 0.3 mm thick. The other end of the flexible connector is clamped on a stud by nuts and washers. Flexible connectors in lead-bushing joints are very convenient, because they make up for the difference in lead length and protect the leads from breakage in transportation.

Leads are clamped in wooden (beech) cleats attached to the top and bottom yoke clamps. One member of a cleat serves as a support and the other as a clamp. Where 35-kV leads are mounted on cleats, the former are wrapped with pressboard sheets 0.5 mm thick to obtain a total thickness of 2 to 4 mm on the side. The cleats are held together by steel bolts and nuts.

It is extremely important to make leads precisely to drawings. Bends in leads and their spacing from other parts, if not properly executed, may adversely affect the whole process of transformer assembly. Cases are known in which departures from drawing instructions (a reduced spacing between leads and yoke clamps, wrong bends, or decreased insulation) have resulted in the breakdown of transformers during tests.

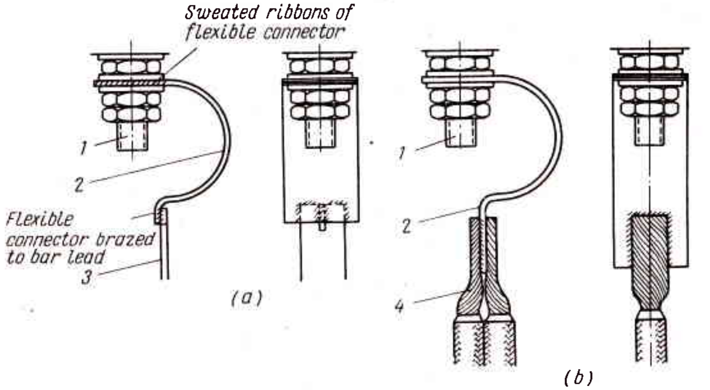

Sweated ribbons of flexible connector
1
2
Flexible connector brazed to bar lead
3
(a)
1
2
4
(b)

Fig. 48. Connection of leads to 35-kV bushing terminals:

a—bar lead; *b*—cable lead; *1*—bushing terminal; *2*—flexible connector; *3*—lead bar; *4*—cable

Fig. 49 shows the core-coil assembly and cover of a Type TM-100/10 transformer. The L.V. leads *1* are mounted in wooden cleats *2*. The H.V. voltage taps *3* are terminated at the tapping switch *4*, while the H.V. line leads *5* are carried to the H.V. terminal bushings. In all of the lead-bushing joints use is made of flexible connectors. The arrangement of connections and the clamping of the leads in wooden cleats are also shown in Fig. 23.

23. Terminal Bushings

In oil-immersed transformers, the windings are connected to the external circuits through porcelain terminal bushings mounted either on the cover or the walls of the tank.

A simple transformer bushing consists of a porcelain cylinder, which is the basis of the bushing, a terminal assembly, and a mounting flange with which the bushing is fastened to the cover or the wall of the tank. The terminal assembly includes the central conductor or terminal and all associated current-conducting fittings.

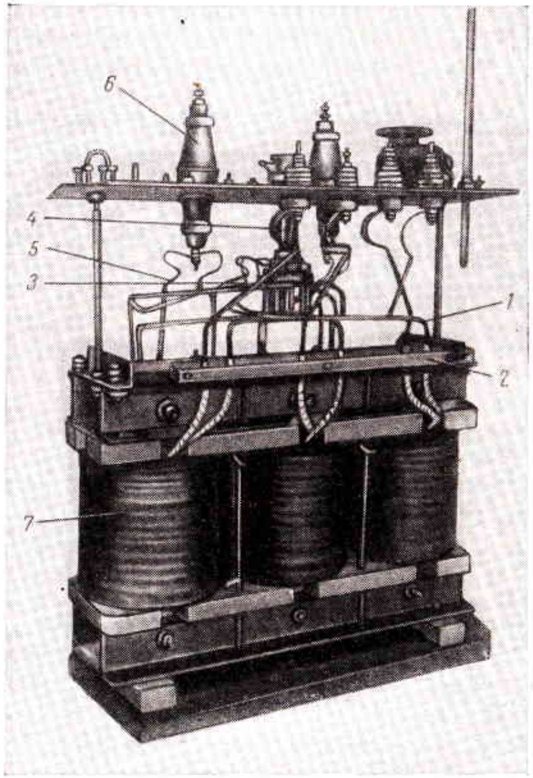


Fig. 49. Core-coil assembly of Type TM-100/10 transformer with cover:

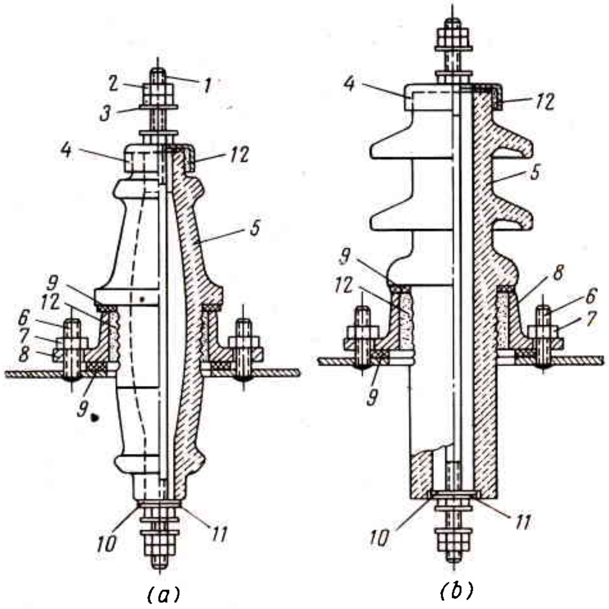
1—L.V. lead; *2*—wooden cleat; *3*—H.V. taps; *4*—H.V. tapping switch; *5*—H.V. line lead; *6*—H.V. lead; *7*—H.V. winding

The lower end, or shank, of the porcelain cylinder fits into the tank, while the other end projects above the cover (see Fig. 23). Bushings for 6 to 10 kilovolts are filled with air, while bushings for 35 kilovolts or higher are filled with transformer oil.

The internal insulation of a bushing is further enhanced by applying insulation (say, a synthetic-resin-bonded paper sleeve) to the terminal (see Fig. 52). External insulation is provided by the porcelain cylinder and the clearance between the top end of the bushing and the metal mounting flange. The electric strength of the external insulation depends on this clearance, decreasing with decreasing clearance.

Terminal bushings may be designed either for indoor or for outdoor service, depending on the design of the porcelain bushing.

A bushing for indoor service (the *plain type*) has either a smooth surface or low corrugations, Fig. 50 (*a*). A bushing for outdoor service must have watersheds or skirts (the *shedded type*), Fig. 50 (*b*).



(*a*) (*b*)

Fig. 50. Terminal bushing for 10 kV, 400 A:

a—for indoor service; *b*—for outdoor service; *1*—copper terminal; *2*—brass nut; *3*—copper washer; *4*—steel cap; *5*—porcelain insulator; *6*—steel stud; *7*—steel nut; *8*—cast-iron flange; *9*—rubber washer; *10*—pressboard washer; *11*—steel washer; *12*—magnesia cement

The purpose of the watersheds or skirts is this. When the outer surface of a bushing is washed by rain, the rain water and the particles of dust and dirt on the bushing form a current-conducting film, and the external insulation of the bushing loses much of its strength. Where watersheds or skirts are provided, the surface of the bushing under the skirts remains dry, and the strength of the insulation is affected less. By providing the requisite number of sheds, it is possible to obtain ample insulation for any atmospheric precipitation.

As will be recalled, any current-carrying conductor produces a magnetic field around itself. A magnetic field is also produced in the cover or the wall of the tank when an electric current flows through the bushing. Because of this, the cover or wall is heated by eddy currents and hysteresis losses.

There exist several methods of controlling the magnetic field in the cover (or wall) of the tank.

First, the openings for the bushings can be made of larger diameter. Then the terminal will be placed farther away from the cover, and a greater resistance will be offered to the magnetic flux. As a result, the magnetic field in the cover will be reduced, and the cover will be heated less. It is always possible to determine the optimum diameter of the openings for a given current.

Second, instead of one, several bushings can be mounted in the same opening. If the bushings mounted in a common opening are connected to the start and finish of the same winding, there will be no flux enveloping both terminals in the cover, because the currents in the bushings are equal in magnitude and opposite in direction, and their resultant magnetic flux will be practically nil. If the three line bushings of a three-phase transformer be placed in the same opening, there will be no magnetic flux around the bushings either, because the sum of the instantaneous values of currents will be zero.

The common opening for two or three bushings is closed by cast-brass covers with as many pockets, Fig. 51.

Fig. 52 shows an assembled 35-kV bushing for outdoor service. The porcelain shell *1* is cemented into a cast-iron flange *5* by magnesia cement *4*. The copper terminal *3* is brazed to a metal cap *18* which is also made fast to the shell by magnesia cement.

At its top the terminal has nuts *16* and washers *15* for connection to the line. At the opposite end the terminal has a pressboard washer *14*, paper-base laminate washer *11*, nuts *13* and washers *12* for connection of the lead.

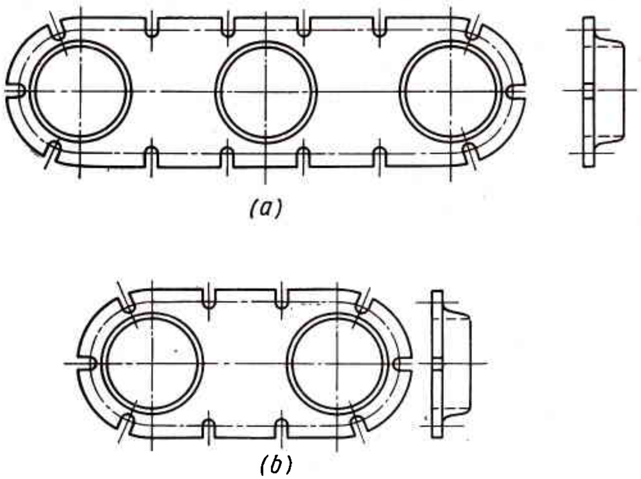


Fig. 51. Brass mounting for terminal bushings:
a—triple; *b*—double

The internal insulation of the bushing consists of a synthetic-resin-bonded paper tube *9* slipped over the terminal, the oil *10* filling the bushing, and the porcelain shell *1*. The external insulation is reinforced by watersheds *2*.

The cap has a threaded hole closed by a screw *17*, washer and asbestos packing. When the bushing is being filled with oil, the screw should be backed off in order to bleed the air displaced from inside the bushing by the oil flowing in through a cut-out in the pressboard washer.

A disadvantage of this type of bushing is that holes have to be made in the cover for connection of the leads to the bushings. Also, when a faulty bushing has to be replaced, much oil has to be drained from the tank, which is often difficult to do under service conditions. In this respect, detachable bushings are more convenient both to install at the factory and to replace in service, because no holes have to be made, nor has much oil to be drained off.

Fig. 53 shows the design of a detachable bushing for 35 kilovolts. The terminal *1* is brazed to the lead *17* and

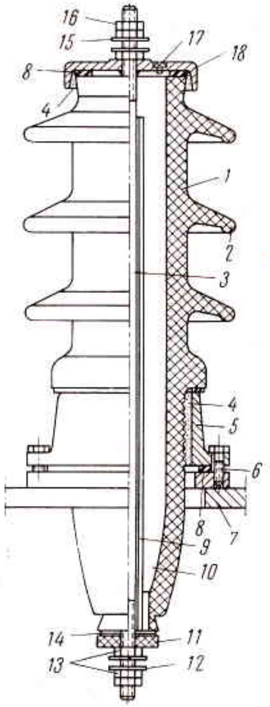


Fig. 52. Terminal bushing for 35 kV:

1—porcelain insulator; *2*—watershed or skirt; *3*—terminal; *4*—magnesia cement; *5*—cast-iron flange; *6*—bolt; *7*—transformer cover; *8*—rubber gasket; *9*—synthetic-resin-bonded paper tube; *10*—oil; *11*—paper-base laminate washer; *12* and *15*—metal washers; *13* and *16*—nuts; *14*—pressboard washers; *17* -screw; *18*—metal cap

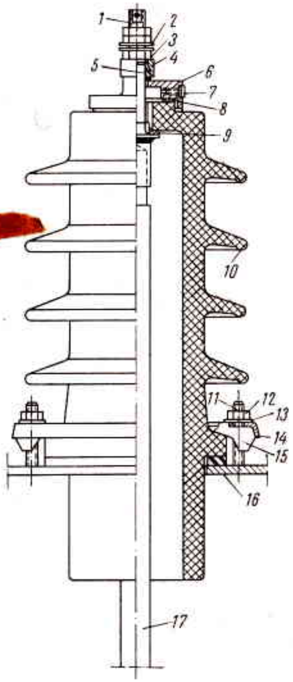


Fig. 53. Detachable terminal bushing for 35 kV:

1—terminal; *2* and *13*—metal washers; *3* and *12*—nuts; *4*—bushing; *5*—rubber ring; *6*—metal cap; *7*—air-bleed bolt; *8*—rubber washer; *9*—seal; *10*—porcelain insulator; *11*—steel stud; *14*—steel flange; *15*—boss; *16*—tank cover; *17*—lead is passed through the top opening in the porcelain shell *10*. On top of the terminal are a cap *6* and a sleeve *4*. The nut *3* applies sealing pressure to a rubber ring *5* and a rubber gasket *8*. When the bushing is being filled with oil, the air displaced from the bushing escapes through the hole otherwise closed by a bolt *7*. The bushing is mounted on the cover on a flange *14* which has bosses *15*. For replacement of the shell, it will suffice to remove the nuts, sleeve and cap from the terminal, and to unscrew the nuts *12* on the mounting flange.

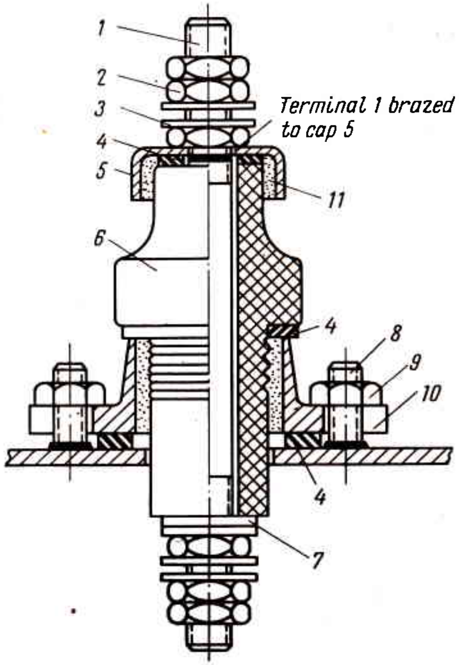


Fig. 54. Terminal bushing for 230-525 V:

1—terminal; *2*—brass nut; *3*—metal washer; *4*—rubber washer; *5*—metal cap; *6*—insulator; *7*—pressboard washer; *8*—steel stud; *9*—steel nut; *10*—cast-iron flange; *11*—magnesia cement

Detachable bushings for 6 to 35 kilovolts are widely used on the recent makes of Size 2 and 3 transformers.

On voltages from 230 to 525 volts (transformers of Size 1 and 2) use is made of flanged bushings cemented with magnesia cement (Fig. 54). No oil is used in these bushings which are equally good for both indoor and outdoor service.

Fig. 55 shows a built-up bushing designed for voltages not over 525 volts and assembled directly on the transformer. It consists of two porcelain shells of which one, *6*, is placed inside and the other, *5*, outside the tank. The terminal *1*, with a rubber washer *9* put on it, is passed through the inside shell which is inserted through an opening in the cover or wall of the tank from inside the tank. The projecting portion of the inside shell fits into the outside shell.

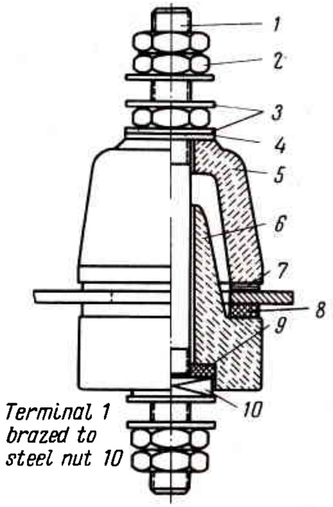


Fig. 55. Built-up terminal bushing for up to 525 V:

1—terminal; *2*—brass nut; *3*—copper washers; *4* and *7*—pressboard washers; *5*—top shell; *6*—bottom shell; *8* and *9*—rubber washers; *10*—steel square nut

Another rubber washer *8* supports the inside shell on the inner surface of the cover, while a pressboard washer *7* supports the outside shell on the outer surface. The shells are held to the cover by tightening the nuts on the top end of the terminal.

Built-up bushings for 525 volts are mostly used indoors. On Size 1 transformers for 6-kV service, bigger bushings of this type are fitted, usually on the tank wall (see Fig. 57).

24. The Tank, Cooling Gear and Oil Conservator

The tank of an oil-immersed transformer, into which the core-coil assembly is placed, is a steel container, most often oval in shape. The shell of the tank is welded to the bottom, while the cover is fastened to a top frame fabricated from steel angles.

Tank design varies with transformer capacity. As stated earlier (see Sec. 16), low-capacity transformers (not over 30 kilovolt-amperes) liberate relatively little heat in operation; the cooling surfaces need not be large, and plain tanks are therefore used.

Fig. 56 shows a 20-kVA, 6-kV transformer in a plain tank. The bushings are mounted on the side walls and covered by hoods as a protection against rain. The transformer is lifted by two lugs provided on the long axis of the tank. To the tank bottom are welded two steel-strip cross members to install and fasten the transformer on a foundation. The level of oil is well below the cover, so the joint between the top frame and the cover may be non-oil-tight.

On capacities 50 kilovolt-amperes and higher, plain tanks cannot radiate all the heat liberated in the transformer, and increased cooling surface becomes necessary. This is done by welding round tubes on to the tank, which gives the so-called tubular tank. The tubes are usually 51 mm in diameter, having a wall thickness of 1.75 mm. For large sizes of transformers (50 to 100 kilovolt-amperes) several tubes are welded on to a wall, so that they occupy only part of the wall's perimeter.

Fig. 57 shows a 50-kVA three-phase 6/0.4-kV transformer placed in a tank *1* which has only a single bank of six tubes. The built-up L.V. *17* and H.V. *18* bushings are mounted on the wall; the hoods over the bushings are not shown. The core-coil unit *11* is supported by channels *12* set up on the tank bottom and is fastened by means of plates *9*, bolts and nuts to the angles *10* welded to the tank walls from inside. At *8* and *14* are the H.V. and L.V. leads, respectively, connected to their bushings, and at *15* is the tapping switch. The tank cover *5* accommodates a thermometer *2*, the operating knob *4* of the tapping switch under a protective hood *3*, and an air-bleed and oil-filling plug *6*. The oil-level gauge *7* and the fuse *16* (see Sec. 25) are mounted on the tank wall.

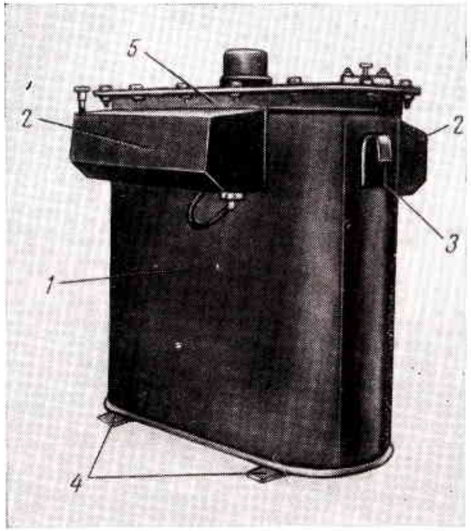


Fig. 56. Transformer for 20 kVA with a plain tank:
1—tank; *2*—hood; *3*—lifting hook; *4*—support plates; *5*—tank top frame

For large sizes of transformers from 630 to 1,800 kilovolt-amperes a single bank of cooling tubes is not enough. Instead, two or three banks are provided. Fig. 23 shows a 1,800-kVA transformer with three banks of tubes.

A new series of Soviet-made transformers in sizes from 60 to 560 kilovolt-amperes (Fig. 58) have elliptical tubes of practically the same perimeter as round tubes 51 mm in diameter. However, the inner area of an elliptical tube is only half that of a round tube. Consequently, the elliptical tubes hold half the weight of oil in round tubes with the same cooling surface. Also, the spacing between elliptical tubes is 20 mm less than in the case of round tubes, so more elliptical tubes can be accommodated on a given tank in a single bank. In fact, a second bank of tubes may well be dispensed with sometimes.

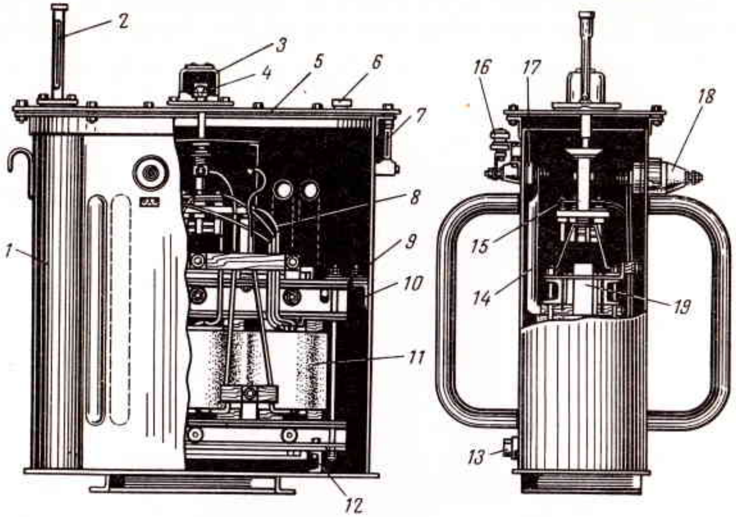


Fig. 57. Three-phase transformer for 50 kVA:

1—tubular tank; *2*—thermometer; *3*—tapping-switch hood; *4*—tapping-switch operating mechanism; *5*—tank cover; *6*—air-bleed and filler plug; *7*—oil gauge; *8*—H.V. leads; *9*—plate; *10*—angle; *11*—core-coil assembly; *12*—channel iron; *13*—oil drain plug; *14*—L.V. leads; *15*—H.V. tapping switch; *16*—fuse; *17*—L.V. terminal bushing; *18*—H.V. terminal bushing; *19*—core

For Size 3 transformers larger than 3,200 kilovolt-amperes even three banks of tubes prove insufficient, and it becomes necessary to employ tubular radiators (Fig. 59) which are attached to the ports welded to the tank wall instead of the ordinary cooling tubes.

A radiator consists of a large number of vertical tubes which provide several parallel paths for the oil circulating in them (Fig. 60). At top and bottom the tubes are welded into headers *1* which communicate with the tank through

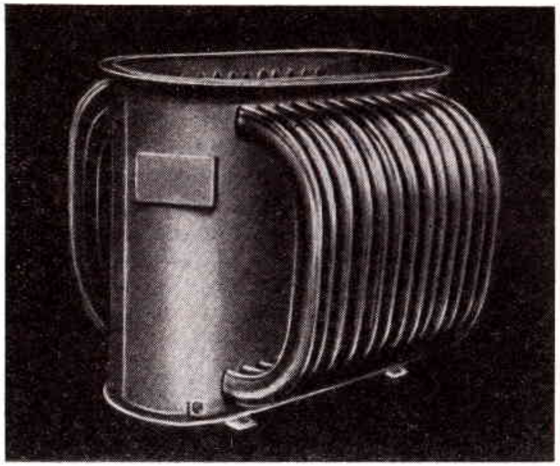


Fig. 58. The tank of a 100-kVA transformer with elliptical tubes

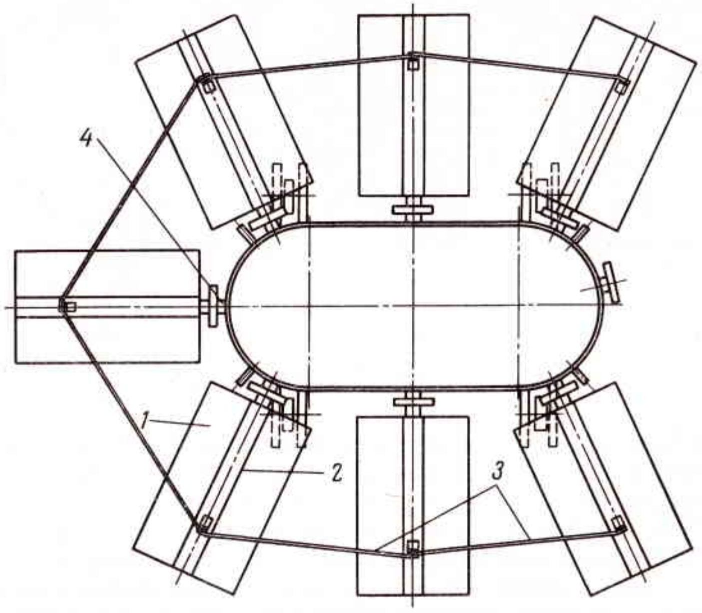


Fig. 59. Arrangement of radiators on the tank of a 5,600-kVA transformer:

1—radiator; *2*—radiator top header; *3*—radiator braces; *4*—port for radiator connection ports. The hot oil from the tank flows into the top header and through the tubes where it gives up its heat. The cooled oil returns to the tank through the bottom header.

In most cases radiators are made detachable for convenience in transportation by rail and in repair.

So that a transformer can be moved around within the substation, units from 100 to 6,300 kilovolt-amperes in size have trucks on rollers (at *18* in Fig. 23). Trucks are either detachable or (more often) welded to the tank bottom. At the factory where assembled transformers are mainly handled by cranes the truck is usually not used.

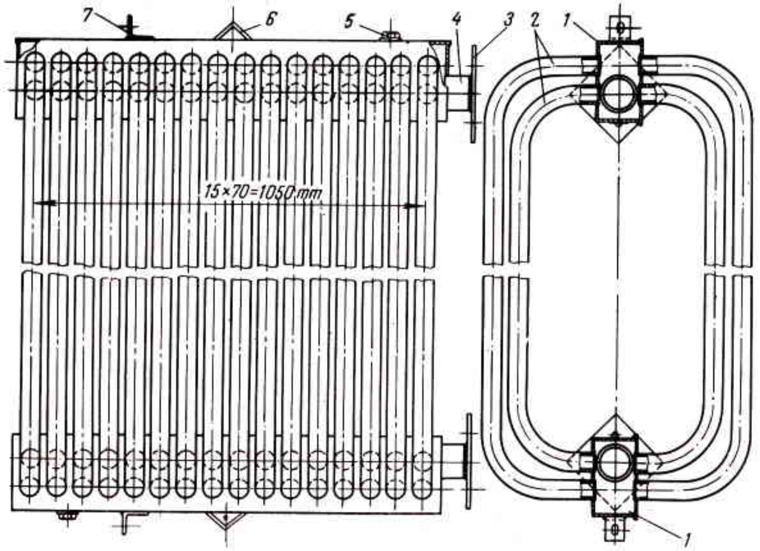


Fig. 60. Tubular radiator with two banks of tubes:

1—header; *2*—cooling tubes; *3*—flange; *4*—port; *5*—air-bleed plug; *6*—lifting angle; *7*—angle for radiator connection

In the tank wall near the bottom there is a plug for taking samples of oil for acidity and electric-strength tests. When oil is to be changed, old oil and sludge are removed through the drain plug in the tank bottom.

All joints in, and attachments on, the tank must be reliably sealed, which takes a good deal of packing material, totalling many metres per tank. In Soviet-made transformers the packing material is a special oil-proof grade of rubber. If of good quality, rubber gaskets and seals prevent any leakage of oil and enhance the reliability of transformers in service.

The oil conservator is an essential feature of oil-immersed transformers, closely related to the tank and cover (Fig. 61). Under USSR State Standard 401-41, conservators are fitted on all transformers over 75 kilovolt-amperes in size. On new transformers, however, they are mounted on sizes from 20 kilovolt-amperes upwards because of the decisive improvement in the performance of conservator-equipped units.

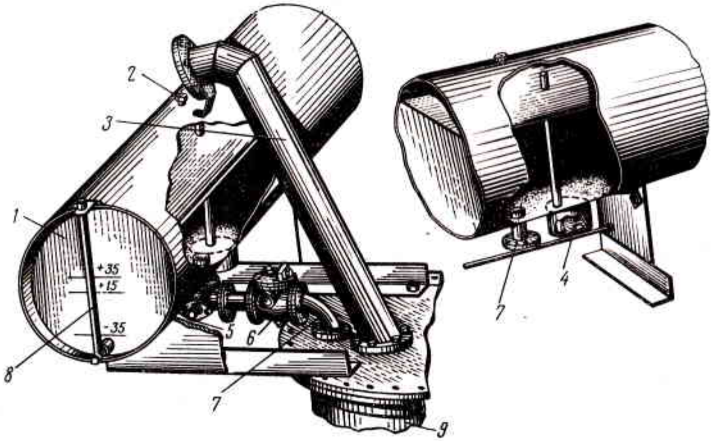


Fig. 61. Mounting of the conservator and the relief stack:

1—conservator; *2*—oil filling plug; *3*—relief stack; *4*—sump; *5*—conservator shut-off cock; *6*—Buchholz (gas-formation) relay; *7*—oil line; *8*—oil gauge; *9*—tank

The purpose of the conservator is this. Transformer oil has a considerable thermal expansion. When a transformer is de-energized, the oil in the tank is at ambient temperature. USSR State Standard 401-41 fixes the lowest and highest ambient temperatures at which a transformer may still be used, —35° and +35°C, respectively. In operation at full load and maximum ambient temperature, the temperature rise of the oil may be as high as 40 degrees, giving an oil temperature of 75°C. Thus, the temperature range of transformer oil is 110 degrees. It has been calculated that over this range the volume of the oil in a transformer may change by 8 per cent.

In the absence of a conservator, the level of oil has to be kept some distance below the top cover in order to provide room for oil expansion with increasing temperature. Because of this, the top surface of the hot oil is exposed to air. Exposure to air speeds up the ageing of the oil due to increased sludge and acid formation through moisture absorption and oxidation.

Where a conservator is fitted on a transformer, the tank is completely filled with oil. The excess oil due to expansion flows into the conservator by a pipe (at *7* in Fig. 61). The relatively small surface of cool oil in contact with air in the conservator reduces the moisture and oxygen absorption, so that ageing is effectively retarded.

The service life of the oil in the tank is further extended by provision of a *breather*, a device which permits the ingress and egress of air in accordance with temperature variations inside the transformer. The breather incorporates a silica-gel *dehydrator* which takes the oxygen and moisture out of the air and an *oil seal* to remove mechanical impurities from the air.

The conservator has a sump *4* where sludge and mechanical impurities are collected for eventual removal (Fig. 61). The sump is welded to the conservator from beneath and has a drain plug. To prevent any sludge and impurities from getting into the main tank, the pipe from the tank projects 20 to 25 mm into the conservator.

A check on the oil level in the transformer both when filling it with oil at the factory and in service is provided by the oil level gauge *8* mounted on the conservator. At one time, Soviet-made transformers were equipped with oil gauges which were connected to the conservator only at the lower end (Fig. 61), while the top end was open to atmosphere.

In the case of a breather, there must be no other contact of the oil with air except in the conservator. This has necessitated connection of the oil gauge to the conservator at both ends (Fig. 62). The joints at both ends of the gauge glass *10* are sealed by rubber washers *6* and *11* and glands *7*. When the glass is to be cleaned or replaced, the flow of oil from the conservator is cut off by a shut-off screw *12*.

Size 1 and 2 transformers use a flush fitting of the glass window pattern. This reflex type of oil gauge is arranged as follows. Two holes 4 mm in diameter are drilled in the end wall of the conservator, and a piece of transparent unbreakable plastic (or armour-plate glass) is put over a gasket so as to cover the two holes. Then a steel bezel is put over the glass and fastened to the wall by two studs welded to it. The space between the glass and the wall is filled by oil to the same level as in the conservator.

This type of oil gauge is very simple, but the reliable seal around the glass can be obtained only when the glass is small in size. Also, the oil level in the oil gauge can be seen only if the attendant stands opposite to the end wall of the conservator; he cannot see the oil level from the side. The glass or the gasket can be replaced only when the oil from the conservator is drained off.

25. Protective Devices and Instruments

Any fault which occurs inside a transformer in operation (insulation puncture, shorted turns, poor contacts, or sparking due to poor earthing) is generally accompanied by the evolution of gas as a result of the decomposition of oil or solid insulation (paper and pressboard).

The gas bubbles rise to the cover, move to the pipe, run to the conservator (for which purpose transformers are set up at an angle away from the conservator) and into the conservator. On its way there, the gas is collected in a device connected between the tank and the conservator. After the gas collected reaches a pre-determined volume, the device gives an audible or a visible warning of the fault. Also, the device trips the circuit-breaker of the transformer when there is a heavy flow of oil from the tank into the conservator. This device is known as the *Buchholz* or *gas-formation relay*.

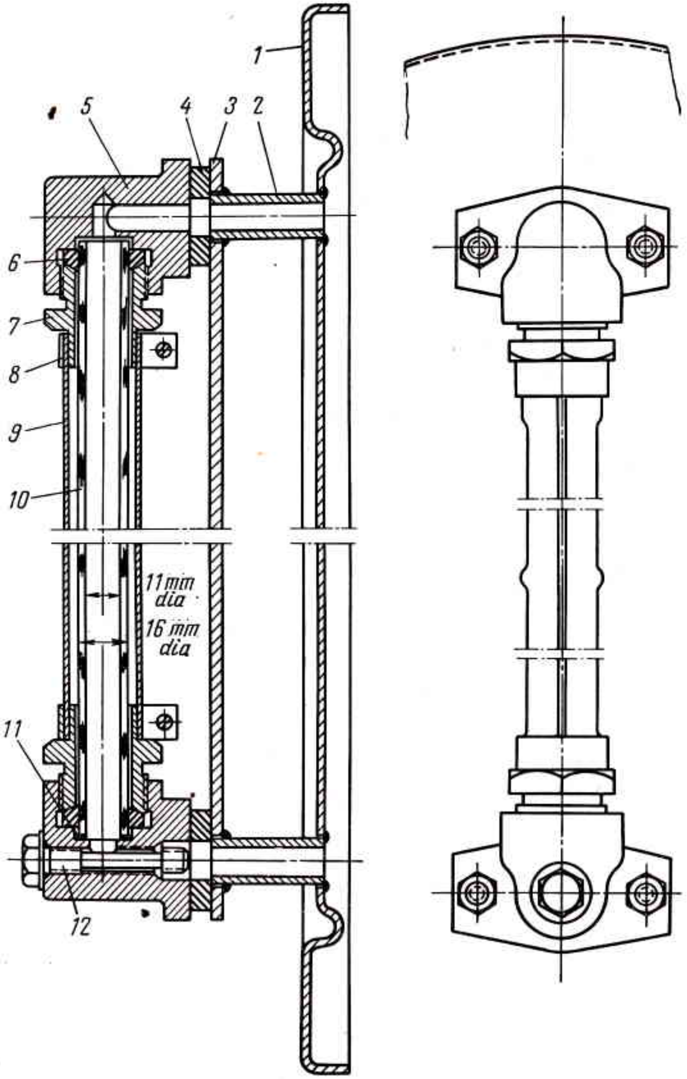


Fig. 62. Oil gauge communicating with the conservator only:

1—conservator wall; *2*—pipe; *3*—plate; *4*—rubber gasket; *5*—elbow; *6* and *11*—rubber washers; *7*—gland; *8*—steel clip; *9*—steel armour; *10*—glass tube; *12*—shut-off screw

A Buchholz relay (Fig. 63) consists of a metal housing *1* and two floats: upper or alarm float *12* and bottom or trip float *15*, arranged inside the housing. The floats carry each a mercury switch, *2* and *5*. Normally, the floats ride on the oil surface, and the switches are open. As gas collects in the housing, it displaces the oil out of it. The top float drops, and its mercury switch completes the alarm circuit on the control board at the substation. In the case of a heavy oil flow into the conservator, the bottom float rises to close its mercury switch, and the tripping circuit is completed to disconnect the transformer from the line, thereby averting a major breakdown.

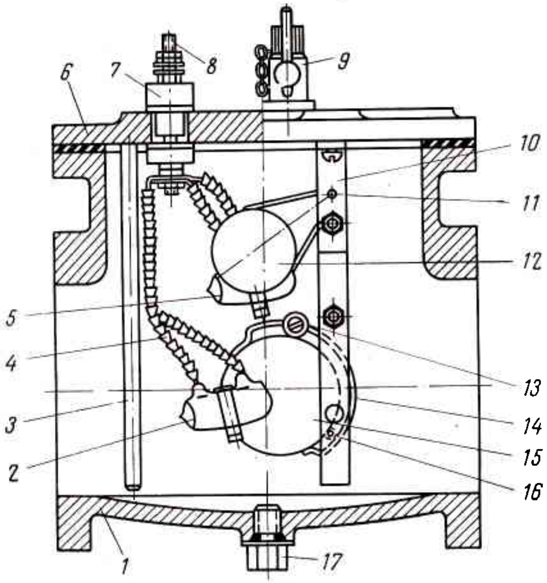


Fig. 63. Buchholz (gas-formation) relay:

1—housing; *2*—mercury switch of bottom (trip) float; *3*—cover rod; *4*—porcelain-bead insulated wire; *5*—mercury switch of upper float; *6*—relay cover; *7*—porcelain insulator; *8*—terminal; *9*—cock; *10*—float frame; *11*—upper-float pivot; *12*—upper (alarm) float; *13*—weight; *14*—bracket; *15*—bottom float; *16*—bottom-float pivot; *17*—drain plug

To avoid serious damage to the tank and gaskets in the case of a strong gas evolution, a device known as the *relief* or *explosion stack* is provided on transformers. The relief or explosion stack (at *3* in Fig. 61) is mounted on the tank cover of transformers of 1,000 kilovolt-amperes and over. It is a long steel pipe communicating with the tank at one end and closed by a disk of thin glass at the other. When the pressure inside the tank rises dangerously due to a grave fault, the disk bursts, and oil and gas are expelled into the atmosphere. If there were no explosion stack, the tank would burst instead.

In the case of a puncture between the H.V. and L.V. windings, the potential of the unearthed circuit connected to the L.V. windings and of the windings themselves might rise to a dangerous value. To prevent this from happenning, H.V. windings for up to 525 volts are fitted with a *spark-gap fuse* (at *16* in Fig. 57).

A spark-gap fuse is so arranged that it has one side earthed and the other side connected to the neutral terminal bushing on the L.V. side (if the L.V. winding is star-connected and has its neutral point brought out) or to any line terminal *a*, *b* or *c* (if the winding is delta-connected).

A spark-gap fuse resembles an ordinary plug-type fuse used on circuits operating on 127 to 220 volts. It consists of a porcelain housing and a head. The housing has two contacts insulated from each other: the central contact which is connected to the L.V. winding of the transformer, and the base contact connected by a mounting bracket to the tank cover (earth). The head, which is screwed into the housing, also has two contacts separated by a perforated mica spacer. One of the head contacts touches the central contact and the other the base contact in the housing. As soon as the potential at the L.V. winding rises (due to a fault), the air gaps in the perforations of the mica spacer break down, and the L.V. winding is earthed.

The spark-gap fuse fitted on L.V. windings for 230 and 400 volts have a breakdown voltage of 351 to 500 volts. The fuse provided on windings for up to 525 volts have a breakdown voltage of 801 to 1,000 volts.

In addition to an oil gauge, transformers are also fitted with thermometers. Transformers under 1,000 kilovolt-amperes in size have mercury-in-glass thermometers with a scale calibrated from zero to 150°C. The bulb of the thermometer is placed in a pocket, a thin-walled steel cylinder open at the top. The pocket is inserted into a hole in the tank cover and clamped in place by bolts on a rubber gasket. The thermometer gives the temperature of the top oil (the bottom end of the pocket is 150 mm below the cover). In order to reduce the temperature differential, the pocket is filled with transformer oil. The emergent portion of the thermometer (at *2* in Fig. 57) is enclosed in a steel hood with two openings.

On the larger sizes of transformers, the temperature of the oil is measured by temperature indicators. A temperature indicator is a remote-indicating resistance thermometer whose contacts close as soon as the oil reaches a pre-determined temperature. The contacts complete an alarm circuit which gives attending personnel a warning of the dangerous condition. On large-capacity air-blast-cooled transformers, the temperature indicator is arranged to start the air-blower motor.

Chapter
3 Materials for Transformers

26. *Electrical Materials Defined*

A great variety of materials go to make a transformer. The essential transformer components are, however, made of those differing from ordinary structural materials in properties, especially in their behaviour in electric and magnetic fields. Therefore they are called *electrical* materials.

The electrical materials used in transformer manufacture may be classed into *conductor*, *insulation* and *core materials*.

Conductor materials are those which have a relatively high electrical conductivity and may be used as carriers of electric current, or conductors.

Insulation materials are those which have a low electric conductivity and may serve as insulation for the live parts of a transformer.

Core materials are those which display high magnetic permeability, for which reason heavy magnetic fluxes can be easily produced in them. They are used for the manufacture of transformer cores.

Thus, electrical materials have a broad gamut of properties. Knowledge of these properties is essential to the intelligent treatment and use of the materials and the reliability of transformers.

27. *Conductor Materials*

The conductor materials most commonly used in transformer manufacture are copper and aluminium, and also brass.

Copper is a highly malleale and ductile metal of reddish-yellow colour. It melts at 1083°C. The density is 8.9 g/cu cm. Copper metal (in the crude state) is extracted from ores.

As a conductor, copper offers the following advantages: a relatively high electric conductivity, i.e., low resistivity (0.0175 ohm-sq mm/m at +20°C), a fairly high mechanical strength and high corrosion resistance in ordinary atmospheres. It can be turned, planed, drilled, pressed, forged, welded and soldered.

The copper used in transformers is of Grade M1 (Soviet classification) which is of 99.9 per cent purity, available as bars, sheet, strip and insulated magnet (winding) wire round or rectangular in section. The most commonly used sizes of bare copper strip are given in Table 1, those of bare round copper wire in Table 2, of insulated round copper wire in Table 3, and of copper bars in Table 4. The nominal cross-sectional area of copper bars in Table 4 is less than the product of the bar sides, because the bars manufactured to USSR State Standard 434-53 have their corners rounded.

Magnet (or winding) wire for transformers is classed according to shape and insulation. Wire sizes are specified in terms of the diameter of bare conductors (i.e., less insulation).

The basic grades of magnet (winding) wire, as specified in ГОСТ 6324-52 and using fibrous covering or combined coverings of fibrous materials and enamel, are:

ПЭЛБОС—wire covered with oil-base enamel and a single layer of unspun cotton
ПЭЛШО—wire covered with oil-base enamel and a single layer of natural silk
ПЭЛШКО—wire covered with oil-base enamel and a single layer of kapron (the Soviet brand of nylon)
ПБ—round wire covered with several layers of cable-paper tape
ПББО—rectangular conductor covered with several layers of cable-paper tape and unspun cotton helically wrapped

ПСД—slow-burning, i.e., heat-resisting, magnet (wiring) wire with a double covering of glass fibre impregnated with a heat-resisting varnish and helically wrapped unspun cotton.

The last grade of wire is widely used in windings for special-purpose transformers.

Aluminium is a ductile metal, silver-white in colour. It melts at 657° C. The density is 2.7 g/cu cm. Aluminium is extracted from bauxite by two operations: the preparation of aluminium oxide and cryolite, and the electrolysis of the aluminium oxide dissolved in a fused mixture of

Table 1

Bare Copper Strip
(ГОСТ 434-53)

Thickness × × width, mm	Cross section, sq mm	Weight, kg per metre	Thickness× × width, mm	Cross section, sq mm	Weight, kg per metre
0.1×30	3	0.027	0.3×50	15	0.134
0.3×10	3	0.027	0.3×60	18	0.16
0.3×20	6	0.053	0.3×80	24	0.214
0.3×30	9	0.08	0.5×12.5	6.25	0.056
0.3×40	12	0.107			

Table 2

Bare Round Copper Wire

Diameter, mm	Cross section, sq mm	Weight, kg/m	Diameter, mm	Cross section, sq mm	Weight, kg/m
2.44	4.68	0.042	7.4	43	0.383
3.05	7.3	0.065	8	50.3	0.446
4.1	13.2	0.118	8.6	58.1	0.514
4.8	17.3	0.161	9	63.6	0.565
5.5	23.8	0.212	10	78.5	0.698
6.5	32.2	0.287	12	113.1	1.01

Table 3

Insulated Round Copper Wire
(ГОСТ 6324-52)

Conductor		Thickness of paper covering on diameter, mm	Tolerance on paper thickness, mm	Weight, kg/m
Diameter, mm	Cross section, sq mm			
2.44	4.68	4.25	±0.3	0.064
3.05	7.3	4.25		0.099
4.1	13.2	4.25		0.158
4.1	13.2	5.8	±0.4	0.179
4.8	17.3	4.25	±0.3	0.206
4.8	17.3	5.8	±0.4	0.229
5.2	21.2	4.25	±0.3	0.236
5.2	21.2	5.8	±0.4	0.26

Table 4

Bare Copper Bars

Thickness × × width, mm	Cross section, sq mm	Weight, kg/m	Thickness × × width, mm	Cross section, sq mm	Weight, kg/m
2.83×30	83.2	0.756	5×80	399.1	3.56
4.4×25	109.1	0.98	6×80	479.1	4.27
4.4×30	131.1	1.18	5×100	499.1	4.45
4.5×40	179.1	1.57	7×80	559.1	4.98
5×40	199.1	1.78	8×80	639.1	5.7
5×50	249.1	2.22	8×100	799.1	7.12
4.5×60	269.1	2.35	10×100	999.1	8.9
5×60	299.1	2.67	12.5×100	1249.1	11.12
6×60	359.1	3.2			

cryolite with other fluoride compounds. Its electrical conductivity is somewhat lower than that of copper. The resistivity at +20°C is 0.0292 ohm-sq mm/m (which is 1.65 times that of copper).

Aluminium can be readily worked by rolling, drawing, spinning, extruding and forging. Files for aluminium should have sharper teeth, while cutting and milling tools should have sharper cutting edges than for other metals.

In ordinary atmospheres aluminium has a high resistance to corrosion. The metal is always covered with a thin film of oxide which protects the underlying metal from further oxidation. Aluminium is much more difficult to solder and weld than copper. In transformer manufacture aluminium is used as bars, round conductors for leads, and insulated round and rectangular conductors for coil winding.

Table 5

Bare Round Aluminium Wire
(ГОСТ 7871-56)

Diameter, mm	Cross section, sq mm	Weight, kg/m	Diameter, m	Cross section, sq mm	Weight, kg/m
5	19.6	0.053	8	50.3	0.136
6	28.3	0.077	10	78.5	0.213
7	38.5	0.104	12	113.1	0.306

Table 6

Bare Aluminium Bars
(ГОСТ 5414-50)

Thickness × × width, mm	Cross section, sq mm	Weight, kg/m	Thickness × × width, mm	Cross section, sq mm	Weight, kg/m
4 × 30	120	0.325	6 × 80	480	1.301
4 × 40	160	0.434	8 × 80	640	1.734
5 × 30	150	0.407	10 × 60	600	1.626
5 × 40	200	0.542	10 × 100	1 000	2.71
5 × 60	300	0.813	12 × 100	1 200	3.252

The most commonly used sizes of round aluminium wire are given in Table 5, while Table 6 gives those of aluminium bar.

Aluminium wire is made in the same standard sizes as copper wire (but with different resistance and weight). The grade designations of aluminium conductors for coil winding include the letter A (for example, АПББО, АПБ, etc.).

Brass is an alloy of copper and zinc. The grade designations of brass include the letter Л which is followed by letters and numerals giving the content of copper and other constituents.

Brass of Grade Л62 (35 to 40 per cent zinc) and of Grade ЛС59 (38-42 per cent zinc and 0.8-2 per cent lead) are widely used in transformer manufacture. Both grades melt at about 920°C. The density is 8.5 g/cu cm. Brass is easier to machine and cheaper to make than copper. Therefore, where electrical conductivity may be traded for hardness (such as in contacts for switching apparatus, mounting hardware, etc.), brass is a better choice than copper.

28. Insulation Materials

The properties of importance in insulation materials are electric strength (which is expressed in terms of breakdown or puncture voltage), ability to absorb moisture from the surroundings, mechanical strength (the maximum load on a specimen which causes its fracture), and thermal stability (the ability of a material to withstand a specified working temperature without appreciable reduction in reliability).

Under ГОСТ 8865-58, all insulation for electric machines and apparatus is grouped on the basis of thermal stability into seven classes (Table 7).

The limiting temperatures (called "hottest-spot temperatures") given in Table 7 are the maximum temperatures which insulating materials can withstand for prolonged periods when used in electric machines and apparatus operating under normal service conditions and under rated load. Insulation of a given class may be used in combination with materials from the lower temperature class,

Table 7

Classes of Insulation on the Basis of Thermal Stability

Class	Temperature limit, °C	Description
Y	90	Materials or combinations of materials such as cotton, silk and paper neither impregnated nor immersed in oil, also other materials or their combinations such as capable of operation at the Class Y temperature
A	105	Cotton, silk and paper when suitably impregnated or coated or when immersed in a dielectric liquid, and also other materials or their combinations such as capable of operation at the Class A temperature
E	120	Certain synthetic organic films, and also materials and their combinations (such as Lavsan*, polyvinyl chloride, etc.) capable of operating at the Class E temperature
B	130	Materials or their combinations such as mica, asbestos and glass fibre with suitable organic bonding, impregnating or coating substances, and also other materials or their combinations, not necessarily inorganic, such as capable of operation at the Class B temperature
F	155	Materials or combinations of materials such as mica, asbestos and glass fibre, with suitable synthetic bonding, impregnating or coating substances, as well as other materials or combinations of materials such as capable of operation at the Class F temperature
H	180	Materials such as silicon elastomer and combinations of materials such as mica, asbestos or glass fibre, with suitable bonding, impregnating or coating substances such as appropriate silicon resins, and also other materials and combinations of materials capable of operation at the Class H temperature
C	above 180	Materials or combinations of materials such as mica, ceramics, glass fibre, quartz, with or without inorganic or silicon binders, as well as other materials and combinations of materials capable of operation at temperatures above the Class H limit

provided that at the temperature of the higher temperature class the composite insulation will not undergo changes in electrical and mechanical properties such as would disqualify the insulation for continuous service.

The insulating materials employed in transformer manufacture include pressboard, paper, wood, varnished cloth, cotton tape, varnishes, enamels, transformer oil, built-up or laminated boards, synthetic-resin-bonded paper tubes and cylinders, and porcelain.

Pressboard, Grade ЭМЦ to ГОСТ 4194-58, is made of unbleached sulphate pulp and is intended for immersion in transformer oil at up to 95°C. It has good electrical properties (electric strength, etc.), increased oil absorption and mechanical strength.

Pressboard 0.5 mm thick is available in rolls 1,000 mm wide. Pressboard 1 to 3 mm thick is made in sheets. Small-size sheets measure 850 mm by 950 mm and 850 mm by 1,100 mm, large-size sheets measure 1,650 mm by 3,800 mm. The density is 0.9 to 1 g/cu cm. The surface of pressboard should be smooth, without holes or current-conducting inclusions. When pressed or cut on guillotine shears, pressboard should not laminate. Pressboard is made into insulating parts for transformers.

Cable paper, Grade K-120 to ГОСТ 645-59, 0.12 mm thick, with a density of 0.76 g/cu cm, is made from kraft pulp of natural tan colour and with coarse-ground fibres. Cable paper is usually treated with transformer oil in order to reduce porosity and increase density. As a result, the oil is broken up among a multitude of narrow canals, which improves the electric strength of the material. Cable paper is used as interlayer and lead insulation in transformers.

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* A Soviet-invented polyester resin which can be formed into filaments and fibres from which textiles are made (resembling Terylene and Dacron).—*Tr.*

Telephone-cable paper, Grade КТ-05 to ГОСТ 3553-60, 0.05 mm thick, having a natural tan colour and a density of 0.8 g/cu cm, is made from kraft pulp. It is used as supplementary insulation between coil layers and on winding wire. Telephone-cable paper is inferior to cable paper in mechanical properties.

Crepe paper, to Specs. ТУ-6-58, 0.5 mm thick, having crinkles across its width, is made from kraft pulp. The density is 0.82 g/cu cm. The elongation is up to 50 per cent. It is used as winding tap insulation.

Beech, to ГОСТ 2695-56, is a deciduous tree having a heavy, hard and strong wood which machines well. In transformers it is used as a structural material. The density is 0.65 to 0.7 g/cu cm. The moisture content in a freshly cut wood is 35 to 45 per cent, which can be reduced to 5-7 per cent by drying. When drying, the temperature should be raised and lowered gradually to avoid cracking due to shrinkage. Beechwood shrinks differently with or across grain. Beechwood increases the acidity of transformer oil less than other woods.

The electrical properties of beechwood can be improved either by impregnation with transformer oil (for oil-immersed transformers) or by coating it with varnishes (for dry-type transformers).

Varnished cloth, to ГОСТ 2214-60, is made from either cotton or silk impregnated with insulating varnish. The fabric provides a fairly high mechanic strength, while the varnish coating gives high electric strength. Varnished silk cloth is stronger electrically, although lighter in thickness, but is more expensive than varnished cotton cloth.

Grade ЛХСМ is an oil-resistant varnished cotton cloth treated with clear varnish. It is made in thicknesses 0.17, 0.2, and 0.24 mm. The density is 1.1 g/cu cm. It is used as winding tap and lead insulation in oil-immersed transformers.

Grade ЛШСС is a special-purpose varnished silk cloth treated with clear varnish. It is made in thicknesses from 0.04 to 0.06 mm and from 0.1 to 0.15 mm. It is used as winding tap and lead insulation in oil-immersed transformers.

Crade ЛХЧ is black varnished cotton cloth available in thicknesses 0.17, 02, and 0.24 mm. The impregnating varnish is an oil-tar variety. It is not oil-resistant, although it has better electrical properties. It may be used as winding tap and lead insulation only in dry-type transformers.

Cotton tape, to ГОСТ 4514-48, as used in transformer manufacture, is usually of two patterns, namely surgical tape (or herring-bone pattern) and linen-finished tape (taffeta pattern).

Surgical tape, which has the same thread count for both warp and weft, has a 45-deg bias which produces the herring-bone pattern. In linen-finished tape, the threads cross at right angles. The thread count is the same for both warp and weft. Cotton tape is usually made in widths from 10 to 50 mm, either 0.45 mm thick (herring-bone pattern) or 0.25 mm thick (linen-finished pattern). Its uses are mechanical protection for insulation and as a binding material during the assembly of the core-coil unit.

Varnish No. 202, to Specs. ВТУ МЭП 766-51, is an oleosynthetic resinous varnish of the coating baking variety. It is obtained by mixing linseed or china-wood (tung) oil and a synthetic resin at high temperatures—a treatment which produces an oil-modified resin. It is used as a core plate varnish for insulating transformer laminations. The varnished laminations are passed through an oven where the temperature is maintained at 250° to 300°C. During the baking (or "stoving") the solvent burns out, and the varnish undergoes polymerization, forming a hard and strong coating which is highly resistant to oil and moisture.

Varnish No. 302 is similar to No. 202 both in uses and effects. The solvent for both is kerosene.

Phenolic varnish, to ГОСТ 901-56, is a solution of so-called one-step phenolformaldehyde resins in alcohol.*

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* Two types of reaction are employed in the commercial manufacture of phenolic-aldehydic resins, usually referred to as one-step and two-step reactions.—*Tr.*

In transformer manufacture phenolic varnish bonds pressboard into built-up parts where thickness in excess of 3 mm is required.

For bonding, the pressboard parts are given a coat of phenolic varnish, stacked up to the requisite thickness and put between the hot platens of a hydraulic press where they are cured at 125° to 140°C under a pressure of 40 kg/sq cm for one or two hours.

ГФ-95 varnish, to ГОСТ 1018-56, formerly No. 1154, an impregnating oil-modified alkyd varnish of the baking variety. It forms a clear and hard coating of high gloss and high resistance to oil. The coating retains elasticity for a long time despite ageing due to temperature. The electric strength of the coating is 70 kV/mm at 20°C, 30 kV/mm at 90°, and 20 kV/mm after 24 hours' immersion in water. The varnish is used to impregnate transformer coils, imparting them high mechanical strength.

The baking is carried out at a high rate, in the presence of air, during 18 hours, at 105°C. For faster baking (8 to 10 hours), Grade МЛ-92 varnish is added. The solvent for ГФ-95 varnish is petrol.

Varnish No. 447, to ГОСТ 6244-52, is a black impregnating oleo-resinous varnish of the fast-baking variety (during 10 hours at 105°C). The coating has good resistance to moisture. It is used to impregnate the coils of dry-type transformers, and also as a coating varnish for insulation and wooden parts in dry-type transformers. The solvent is petrol.

БТ-99 varnish, to ГОСТ 8017-56, formerly the 462-П, is a black impregnating oil-tar varnish of the air-drying variety. It produces a good moisture-resistant coating on the impregnated coils and leads of assembled dry-type transformers. The solvent is petrol.

ГФ-92/ГС enamel, to ГОСТ 9151-59, formerly СПД enamel, is a baking enamel of grey colour, consisting of a suspension of pigment in alkyd varnish with an addition of drying oil and solvents.

The enamel forms a glossy coating resistant to oil and moisture, having a high mechanical strength and giving good protection to the main insulation against transient

surface discharges. The electric strength of the coating is 30 kV/mm. The enamel dries during 3 hours at 105° to 110°C. It is used to impregnate the coils of dry-type transformers operating in locations with increased humidity, and also to coat the leads and parts of assembled transformers. The solvent is high-flash naphta.

Transformer oil, to ГОСТ 982-56, obtained by fractional distillation of petroleum, has a density of 0.9 g/cu cm. It doubles as an insulation and a cooling agent transferring heat from the hot parts of a transformer (the coils and the core) to the tank walls.

As an insulator, oil backs up the solid insulation between the H.V. and L.V. windings and raises the insulation level of the transformer as a whole. A good grade of oil should have high electric strength, which implies complete freedom from moisture and mechanical impurities.

As a cooling agent, oil should have low viscosity in order to be capable of circulating freely between the hot and cold parts of the transformer. At 50°C its viscosity is as low as 9.6 centi-stokes, and it can efficiently perform its function.

The flash point of oil should be not lower than 135°C, and the freezing point should be not over —45°C. Before filling a transformer with oil, the oil should be additionally dried and filtered. The breakdown voltage of fresh transformer oil should be at least 40 kilovolts for the 2.5 mm spacing of a standard rod-gap.

Built-up or laminated boards, to ГОСТ 2718-54, consist of sheets of impregnated paper bonded together with phenolformaldehyde resin. The density is 1.3 to 1.4 g/cu cm. They may be used for operation both in air and in transformer oil.

The following grades of built-up or laminated boards are used in transformer manufacture:

Grade А—for immersion in transformer oil;

Grade Б—same, but with an increased electric strength along laminations;

Grade В—for operation both in air and in transformer oil;

Grade Г—for operation in air at elevated humidity.

Laminated boards can be easily sawn, drilled, turned and milled. Under 50 mm in thickness, the material is made in sheet form. High-voltage transformers use Grade ЭТ of laminated boards made to Tentative Specs. ИЖ-29-59.

Synthetic-resin-bonded paper tubes and cylinders, to ГОСТ 8726-58, are made of bakelite-coated sheets of paper wound on mandrels. The diameter of the mandrel used determines the inside diameter of tubes and cylinders. During the winding operation, the paper is passed with its unvarnished side over the hot rolls of the winding machine. The tube or cylinder wound on its mandrel is then cured in an oven.

The following grades of synthetic-resin-bonded paper tubes and cylinders are manufactured:

Grade ТБ—inside diameter, 6 to 80 mm; length, up to 1,200 mm;

Grade ЦБ—inside diameter, 85 to 1,500 mm; length, up to 2,000 mm.

Synthetic-resin-bonded paper tubes and cylinders can be drilled, cut, turned and milled. Grade ТБ tubes are used in transformer cores and as lead insulation. Grade ЦБ cylinders are employed as formers for the coils of Size 1 through 3 and special purpose transformers.

Porcelain, to ГОСТ 5862-51, is a key ceramic material widely used in the manufacture of insulators. Large pieces, such as transformer bushings, are made by the so-called wet process from a wet plastic mixture of kaolin, ball clay, quartz and felspar shaped on a potter's wheel and turned on a lathe. The "green" products are then dried, coated with glaze for strength and fired in a kiln at 1320° to 1350°C.

29. Core Materials

Transformer cores are made from so-called electrical sheets and strip available in a variety of grades. The steel used for the purpose is known as electrical-sheet steel, or iron.

Electrical-sheet steel, to ГОСТ 802-58, is a silicon alloy with silicon content ranging from 0.8 to 4.8 per cent. Silicon increases the magnetic permeability of steel in weak magnetic fields and increases its resistance, thereby reducing eddy-current losses. Electrical-sheet steel is produced in open-hearth furnaces.

Sheets are manufactured by rolling steel ingots either in the hot or in the cold state. Accordingly, there are hot-rolled and cold-rolled sheets. A relatively recent development in the production of high-quality strips for transformer cores is cold-reduced oriented silicon steel. By special cold rolling (or reduction) and intermediate annealings in a hydrogen atmosphere, the crystallites of the steel are so oriented that high permeability and low loss are ensured in the rolling direction. While for hot-rolled transformer sheets the maximum induction is 14,500 to 15,000 gauss, the figure for cold-reduced oriented silicon sheets is up to 17,000 gauss, so that both the weight and size of transformers can be appreciably reduced.

Soviet transformer makers use hot-rolled sheets of Grades Э41, Э42 and Э43, and cold-reduced sheets of Grades Э310, Э320 and Э330.

The grade designations of electrical sheets are read as follows:

Э stands for electrical sheet steel. The numeral (1, 2, 3 or 4) immediately after the letter Э gives the silicon content:

1—low-alloy steel (0.8 to 1.8 per cent silicon);

2—medium-alloy steel (1.8 to 2.8 per cent silicon);

3—medium-to-high alloy steel (2.8 to 4 per cent silicon for hot-rolled sheets and 2.5 to 3.5 per cent silicon for cold-reduced strip);

4—high-alloy steel (4 to 4.8 per cent silicon).

The second numeral (1, 2 or 3) gives a relative indication of the standard core loss (watts per kilogram)* as follows:

1—normal core lossess;

2—reduced core losses;

3—low core losses.

The zero at the end of a grade designation signifies that this is cold-reduced steel.

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* Standard core loss is defined as the total power in watts consumed in each kilogram of material at standard temperature when subjected to an alternating magnetizing force so as to produce an induction between specified limits of opposite sign at standard frequency.—*Tr.*

Electrical sheets are available in thicknesses of 0.35 and 0.5 mm. Cold-reduced strip is made in a thickness of 0.35 mm.

30. Auxiliary Materials

Transformer manufacture also uses a number of auxiliary materials such as solders, soldering fluxes, rubber, decorative enamel, primer and nitrocellulose lacquer.

Solders are alloys of two or more metals used for joining metals (wires, etc.) together by melting a suitable alloy into the joint. Since solders have a lower melting point than the metals to be jointed, the metals do not melt. The molten solder fills the voids in the joint and, on solidifying, unites the metals. This process is called *soldering*. There are two general methods of soldering, namely, *soft soldering* and *hard soldering*, or *brazing*. Accordingly, there are *soft solders* and *hard solders*, or *spelter solders*.

Soft solders melt at not over 350°C. They consist chiefly of lead and tin, although other metals are occasionally added to lower the melting point. In the Soviet Union soft solders are made to ГОСТ 1499-54. The numerals in the grade designations of solders give an approximate tin content. The most commonly used soft solders are:

ПОС-30 of the composition: tin, 30 per cent; antimony, 2 per cent; lead, remainder. It melts at 256°C and is used to tin copper-ribbon leads.

ПОС-40 of the composition: tin, 40 per cent; antimony, 2 per cent; lead, remainder. The melting point is 235°C. It is used to join winding wire of small cross section and transformer coil leads.

Hard or spelter solders are employed where stronger joints are essential. Brazing is done at 530° to 720°C. The most commonly used grade of hard solder is ПМФ-7.

ПМФ-7 is an alloy of 92.5 per cent copper and 7.5 per cent phosphorus. It melts at 715°C and is used to braze winding wire and transformer leads made of round and bar copper. As the phosphorus content increases, the material becomes more brittle and its melting point rises.

Soldering fluxes. If a soldered joint is to be strong and sound, it is essential that an alloy be formed between

the metal and the solder. This requires that the surface of the metal be entirely free from foreign substances, such as oxides, oils, or various kinds of solid matter. This is accomplished by using a flux that melts at the fusing temperature of the solder to dissolve the oxide film and to exclude the air from the joint. The most commonly used fluxes are colophony or rosin, borax, boracic acid, sal-ammoniac and zinc chloride.

Colophony or rosin fuses at 68° to 70°C and dissolves in alcohol. It is a cheap and easy-to-get material.

Borax is a white crystalline powder fusing at 741°C. It is used either alone or in a mixture with boracic acid.

Rosin, sal-ammoniac and zinc chloride are made into what is known as soldering paste of the following formula (parts by weight):

Rosin	64
Stearine	64
Zinc chloride	45.5
Sal-ammoniac	9
Vaseline	100
Water	18

Soldering paste is made as follows: the zinc chloride and the sal-ammoniac are dissolved in the water. The rosin and the stearine are melted over a low flame while stirring, until a creamy mass is obtained into which the zinc chloride and sal-ammoniac solution is poured. The mixture is stirred until a uniform and thick paste is obtained. The vaseline is then added to the paste while it is warm, and this is again stirred thoroughly. The ready paste is poured into moulds measuring about 250 mm in length and 15 mm square in section and is allowed to solidify.

Oil-resistant transformer rubber, to Specs. ТУ 1567-49 and ТУ 233-54 is used in transformers in the form of gaskets, joint seals and the like. It is available in plates from 2 to 16 mm thick, 500 to 960 mm wide, and 500 to 5,000 mm long. Resistance to oil is essential because it comes in contact with transformer oil at up to 95°C. In the case of rubber not resistant to oil, oil would dissolve the sulphur found in the rubber and might cause trouble if the sulphur were allowed to attack the copper.

After 24 hours' immersion in transformer oil at 100±5°C, rubber plates should swell not more than 10 per cent by weight. The plates should neither laminate nor become smeary on the surface. The hardness of rubber plates should be 45-62 Shore.

Decorative enamel, Grade ФСХ-23, to ГОСТ 926-52, is a suspension of finely divided pigments in alkyd varnish with additions of drying oils and solvents. The enamel is of grey colour. It dries in air inside 1.5 hours at 80°C. The solvent is petrol.

Primer No. 138, to ГОСТ 4056-48, is a suspension of pigments in alkyd varnish. The primer is of red-brown colour. The drying time at 100 to 110°C is inside 35 minutes. It is used on transformer parts and units (tanks, covers, conservators, etc.) preparatory to painting with Grade ФСХ-23 enamel.

Grey nitrocellulose lacquer No. 624-C, to ГОСТ 7462-55, is a solution of nitrocellulose in organic solvents with additions of resins, plasticizers and pigments. The drying time at 18 to 22°C is inside 8 minutes. It is used on the inside surfaces of transformer tanks, covers and conservators coming in contact with oil. The lacquer uses thinner No. 646.

Chapter

4

Assembly of the Core-coil Unit (Stage One)

31. General

The purpose of transformer assembly is to put together transformer parts and units into a single whole. The process of assembly consists of a number of operations, such as assembly of the windings on the core, reblading (stacking up) of the top yoke, assembly and soldering of leads and connections, assembly of the bushings, mounting of the transformer accessories on the tank cover, tanking of the core-coil assembly. These operations differ in the way they are carried out and in the purpose they serve. Therefore, it is customary to divide transformer assembly into three stages, each performed in a separate bay or production area.

The assembly of the core-coil unit (stage one) involves operations necessary to unblade (take apart) the top yoke, to install the insulation, to place the L.V. and H.V. coils on the core, and to reblade (stack up) and clamp up the top yoke.

The assembly and soldering of the leads and connections (stage two) involves operations necessary to assemble and make the winding connections, voltage-control taps and line leads, and to insulate the leads.

The tanking of the core-coil assembly (stage three) involves operations necessary to finish the core-coil assembly after drying, to mount the transformer accessories and fittings on the tank cover, to set up the terminal bushings, to connect up the leads and taps to the bushings and the tapping switch, to lower the core-coil assembly into the tank, and to fill the tank with oil.

Standing somewhat apart are operations necessary to dismantle, finish and hand over the transformer for dispatch after the tests. Some parts on Size 3 transformers have to be dismantled prior to despatch because of the limitations imposed by the railway loading gauge. The final operation is the finishing of the transformer after the parts to be shipped separately have been dismantled and packed.

The division of transformer assembly into stages under factory conditions facilitates planning and supervision. Within each stage, work is done to a definite sequence, which fact contributes to high efficiency and workmanship.

The assembly of every transformer type would be impossible to discuss separately because of the great multitude of makes and designs available, especially in Sizes 1 through 3. Nor would it be reasonable, because the main operations of transformer assembly are almost the same for all types and sizes: the top yoke has to be unbladed in all transformers, the windings are worked and mounted in much the same way, as is the insulation, and the top yoke is clamped similarly.

For our discussion, the most representative types of transformers have been chosen with the maximum number of operations common to the assembly of a given transformer size. Where transformer assembly differs from the general pattern, such as in the case of 35-kV three-phase transformers, moving-coil voltage regulators and some others, emphasis will be placed on the difference.

The parts that come for the first stage of assembly include the core, the L.V. and H.V. coils, the insulation, and packing strips and bars. Whatever the transformer type, the core comes fully assembled and complete with all the accessories. Before the coils can be placed on such a core, the accessories have to be dismantled and the top yoke unbladed.

At first sight it may seem that this is a waste of labour and time: the stacked-up yoke is unbladed to be rebladed again. Yet, there is some reason for this. When being stacked up for the first time, the yoke is placed on the side, and the worker can conveniently fit the laminations to one another, avoiding excessive gaps at the joints, so when the yoke is rebladed a better interleaving can be obtained. Also the assembled core is easier to handle and it takes less storage space. However, when cores are manufactured on a mass scale by flow-line methods, it is more advantageous not to stack up the yoke until after the coils have been placed on the limbs.

For convenience in the assembly of transformer cores, those for transformers of up to 100 kilovolt-amperes in size should be set up on benches 600 mm high, of up to 400 kilovolt-amperes on benches 350 mm high, and cores for transformers in the 630- to 1,000-kVA class should be put on the floor next to the work station. As to sizes in the 1,600- to 6,300-kVA range, the assembly floor should be equipped with suitable cradles and other fixtures.

It is essential that the assembly floor be level, i.e., free from low or high spots. Even the slightest waviness of the assembly floor may cause considerable displacement of the limbs relative to each other. This would be an intolerable condition, since there would be excessive gaps at the joints after the top yoke is rebladed. The total length of such gaps would be equal to the displacement of the limbs, and, if allowed, excessive gaps would cause an increase in the exciting current.

32. Tools for Transformer Assembly

Transformer assembly involves the use of a variety of tools and fixtures, all of them contributing to efficiency and workmanship. Special tools will be described together with the operations done in the first, second and third stages of assembly. Here we shall be concerned with general-purpose tools which are frequently used and must therefore be always at hand.

Bench Vise. The bench vise is used to hold a piece or part while it is being sawed, filed, chiseled or otherwise worked on. It is simple and convenient to use. When the handle is turned a screw in the base of the vise moves the movable jaw towards or away from the stationary jaw, while keeping them parallel. To avoid marring or otherwise damaging the finished surfaces of parts that are to be clamped in the vise, caps of soft metals, such as copper, brass or aluminium, are placed over the steel jaws. They are usually referred to as "soft" jaws.

Hand vises come in useful for clamping small pieces for filing, drilling or assembly.

C-cramps are among the simplest clamping and holding tools used to hold parts in place during assembly.

Hammers, made of tool steel (Soviet grades are У7 and У8), may have either a round or a square face and an oval hole in the centre for a handle. The face is hardened. The handle is made of hard woods (maple, dogwood or mountain ash). Assembly hammers weigh 300 to 600 grams.

Cold chisels are made of tool steel (the Soviet grade is У7A), octahedral or oval in section. The cutting edge is hardened and tempered for a length of 20 to 30 mm. Cold chisels are used for cutting metals, removing burrs, etc., by driving with a hammer.

Files are made of tool steel (the Soviet grades are У8 and У13) or chrome steel (the Soviet grades are ШХ6, ШХ9 or ШХ15), quenched to a high hardness. According to shape, files are classed into flat, square, three-square, round, etc. According to grade of cut, files are classed into rough, coarse or bastard (i.e., coarse-cut) and into second-cut, smooth, dead-smooth or super-smooth (i.e., fine-cut). Files are used for removal of a thin layer of metal, and for cleaning of contacts and leads at the joints to be soldered.

Screwdrivers are made of tool steel (the Soviet grade is У7). They are used for driving, or turning, screws by the slot in their heads which may be round, fillister or countersunk. The blade of a screwdriver should be sharpened so that it will not tend to rise out of the screw slot when it is turned.

To speed up work, use is made of screwdrivers clamped in the chuck of a drill. With such as screwdriver, screws can be rapidly turned and unturned, since it has a double helix and a pawl for reversal of rotation. Screws more than 6 mm in diameter are turned by air- or electric-operated screwdrivers which are fitted with a slip clutch for adjustment of tightening force.

Spanners, or tools for turning nuts and bolts, may be open-end, ring, adjustable and box.

Open-end and ring spanners are available with different

sizes of openings at their ends and are designed for use on plain work where there is no interference. It is essential that the size of the opening be the same as the size of the nut or bolt head. Adjustable spanners have a movable jaw which can be opened by means of a toothed rack and a worm to accommodate different sizes of nuts or bolts. In transformer assembly, however, they are less convenient than the open-end type since, because of the larger head, bolts and nuts in restricted spaces are difficult to reach. Also, the adjusting nut of the spanner may move of its own accord, increasing the opening of the jaws, and the spanner will slip off the nut or bolt.

Box spanners come in useful where bolts and nuts are set flush (in counterbores or holes) and it would be impossible to reach them with the ordinary type of spanner. Also, box spanners are often used on open nuts and bolts for the reason that, once put on a nut, a box spanner need not be repositioned each swing. Instead, it is turned by changing hands on its tommy-bar, speeding up the work. Furthermore, a box spanner encloses a nut from all sides and would not slip off, even though the pull at the spanner may be great. When air- or electric-operated, box spanners make efficient power bolt-drivers.

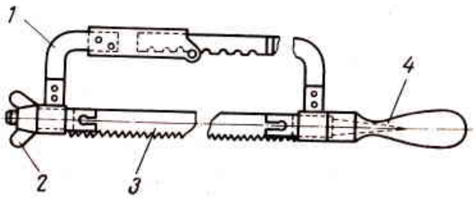


Fig. 64. Hack-saw:

1—frame; *2*—tension-screw wing-nut; *3*—blade; *4*—handle

Pliers are pincers having long jaws, which may be flat or round, for bending wire, holding small objects, etc. They are made of plain carbon steel (the Soviet grade is Steel 50). The jaws are quenched and tempered to the requisite hardness.

There are also **nipper pliers**, or **nippers**, for cutting wire, small-diameter rods, etc. They are made of tool steel (the Soviet grade is У7). The cutting edges are quenched, tempered to the requisite hardness and sharpened.

Hack-saws are saws using a narrow blade (Fig. 64) set in a frame fitted with a handle and a tension screw with a flynut. The blade should be set in the frame so that the teeth point away from the handle, and proper tension is applied to it. Hack-saws are used to cut off small blanks or parts, to trim bolts and studs, etc.

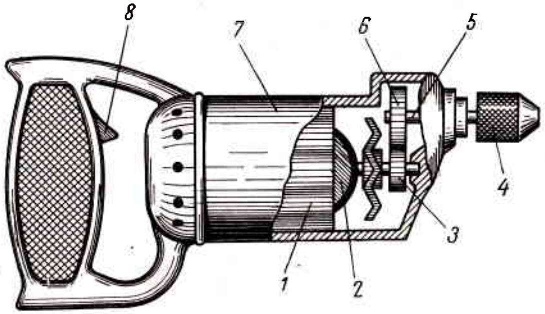


Fig. 65. Electric-operated portable drill:
1—motor; 2—armature; 3—small gear; 4—chuck; 5—spindle; 6—large gear; 7—casing; 8—switch

Portable drills are used for on-the-spot drilling of holes in transformer assembly. They may be electric (Fig. 65), air (Fig. 66) or hand-operated (Fig. 67). Electric drills must be earthed when being used.

The measuring devices most widely used in transformer assembly are: a steel scale, calipers, and vernier calipers.

The **steel scale** is a strip of hardened spring steel 150 to 1,000 mm long, graduated and numbered in millimetres and centimetres on one side. It is used for measuring outside and inside dimensions and distances. For long objects, use is made of folding rules and tape measures.

Calipers may be outside and inside. As the name implies, outside calipers are used to make external measurements on cylindrical pieces, and inside calipers for measuring the diameter of holes, the width of slots, etc. The outside

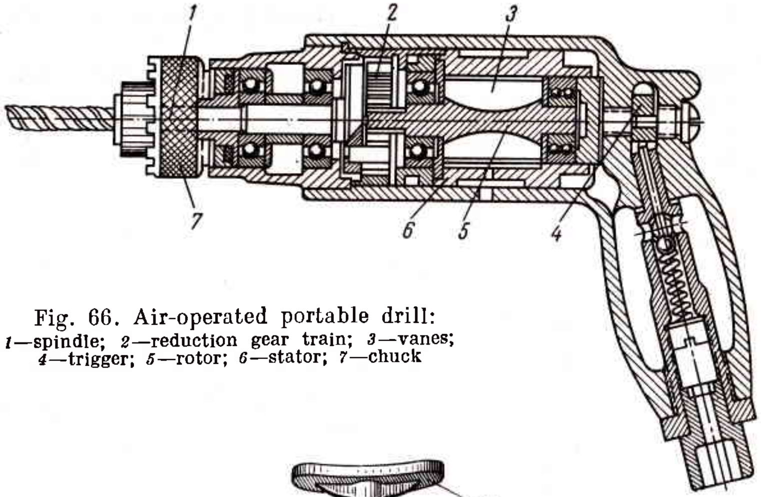


Fig. 66. Air-operated portable drill:
1—spindle; 2—reduction gear train; 3—vanes; 4—trigger; 5—rotor; 6—stator; 7—chuck

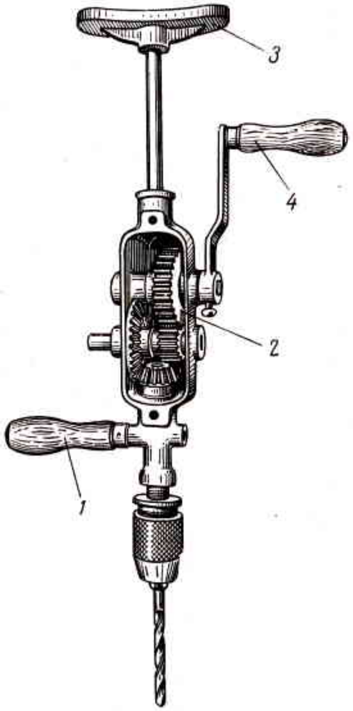


Fig. 67. Hand-operated drill:
1—stationary handle; 2—gear transmission; 3—breast-plate; 4—crank

caliper should be adjusted to slip over the cylindrical piece being measured easily of its own weight. The inside caliper should be entered in the hole and adjusted until it will slip in the hole with a slight drag. After the caliper

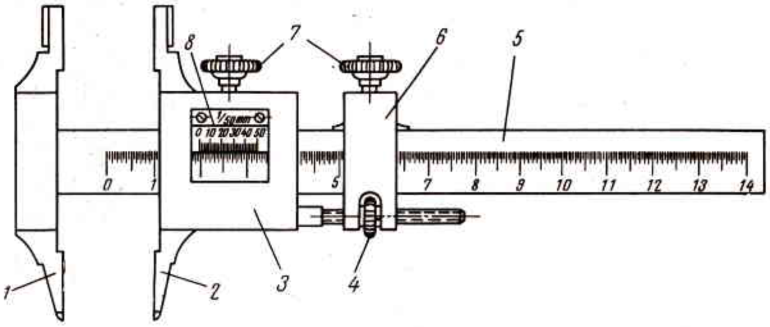


Fig. 68. Vernier caliper:

1—fixed jaw; *2*—movable (gauging) jaw; *3*—slide; *4*—adjusting screw and nut to impart fine motion to gauging jaw; *5*—blade; *6*—crosshead; *7*—clamping screws; *8*—vernier scale

(either outside or inside) is adjusted, it is placed against a scale, and the measurement is read from it.

Calipers are made of tool steel (the Soviet grades are У7 and У8), with the legs quenched for a distance of 20 mm.

Vernier calipers (Fig. 68) can be used to take both outside and inside measurements with an accuracy unattainable with the scale, outside or inside calipers. Vernier calipers are made of carbon or alloy steel.

33. Unclamping the Top Yoke

Before the top yoke can be unbladed, it must be unclamped. To do this on Size 1 and 2 transformers, the nuts are undone on the top yoke clamps and the lifting-rod plates or angles are removed.

Using a box spanner, the top nuts are run off the vertical tie-rods, then the nuts on the yoke studs are broken loose in turn and unscrewed on one side, and one of the clamps is taken down. Then, while holding the other top yoke clamp with the left hand, the yoke studs and synthetic-resin-bonded paper tubes are pulled from the top yoke, and the other clamp is taken down.

On Size 3 transformers (Fig. 69), temporary studs *2* (20 mm in diameter and 680 mm long) are inserted into the outer holes *1* in the top yoke clamps. The temporary studs should be threaded on both ends for a distance of 200 mm, so that they can be used on different core sizes. Nuts are run onto the temporary studs to within 20 or 30 mm of the yoke clamps. After unclamping, the temporary studs and nuts will hold the top yoke clamp on the core until it is taken off by crane.

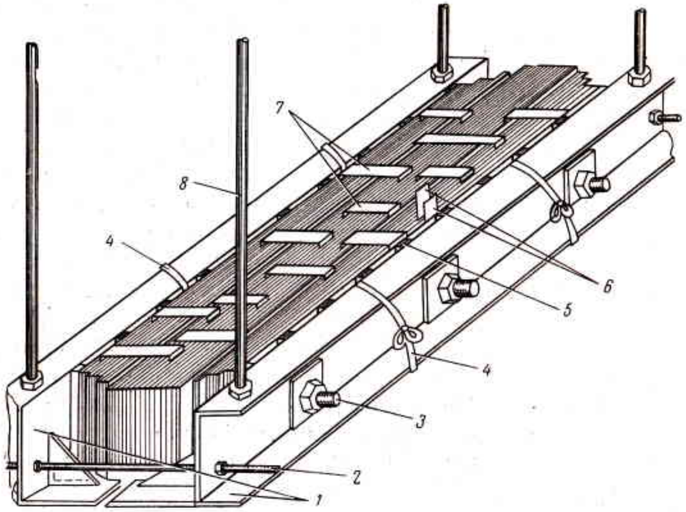


Fig. 69. The top yoke of a Size 3 transformer prior to unblading:

1—yoke clamps; *2*—temporary stud; *3*—yoke stud; *4*—herring-bone tape; *5*—insulating spacers; *6*—earthing ribbon; *7*—U-cramps; *8*—lifting rod

Using a box spanner, the nuts on one end of the yoke studs *3* are then run off, and the steel and laminated paper washers and bushings are pulled from the yoke studs. While holding up one of the top yoke clamps with a crane, the temporary studs are removed and the clamp is taken down to be landed in a designated area in the assembly bay. Then the nuts are run back onto the temporary studs, and the studs are stowed away on a rack for further use.

To take down the other top yoke clamp, it is pulled up with a crane and the yoke studs are taken out together with synthetic-resin-bonded paper tubes, taking care not to damage them. Sometimes, the paper tubes may be jammed in the holes by the steel laminations of the top yoke. Then the tubes must be knocked out of the holes by means of a suitable drift. At the same time, the earthing strip *6* must be removed from the top yoke. All the parts removed should be returned onto the yoke studs.

To keep the laminations from falling out of the unclamped top yoke, U-cramps *7* are applied. They should be staggered and inserted between the laminations so as not to damage the core-plate insulation with their sharp edges.

Between the top yoke and the top yoke clamps there usually are pressboard spacers *5* rivetted to a pressboard sheet as long as the yoke clamps and as wide as the clamps' height. The spacers and the sheets form oil ducts for cooling the side surfaces of the yoke. Before removing the top yoke clamps, the sheets and spacers should be banded with tape *4* (Fig. 69) to the top yoke clamps and removed together with them.

34. Unblading the Top Yoke

The top yoke is unbladed by hand. The operation consists in that the laminations *1* are pulled out in packets, starting with the outer plates, and the packets are stacked up on a bench (Fig. 70) in the case of Size 1 and 2 transformers. The laminations of Size 3 transformers are stacked up on special cradles.

The point that should be observed while unblading the top yoke is this: the laminations should be stacked in order as they are removed. This is essential because the laminations differ in length or, if they are of the same length, in the spacing of holes. So each plate must go back into the same position in the yoke as when the core was originally built. Also care must be taken not to damage the core-plate insulation.

In the case of Size 1 and 2 transformers, the top yoke plates may be removed nine to twelve at a time. The top yoke of a Size 3 transformer should be unbladed, depending on how it was originally stacked up, i.e., two or three plates at a time.

The top yoke of transformers in sizes above 1,000 kilovolt-amperes is usually unbladed from both sides simultaneously, removing the U-cramps from the yoke as the unblading progresses. Since the workmen on either side will not always keep the same pace, one may take more plates than the other. To avoid misplaced plates on reblading, the position of the last-removed core plate should be marked with a length of tape inserted between the stampings of a limb. If the core has a single cooling duct, it may serve as a line of division.

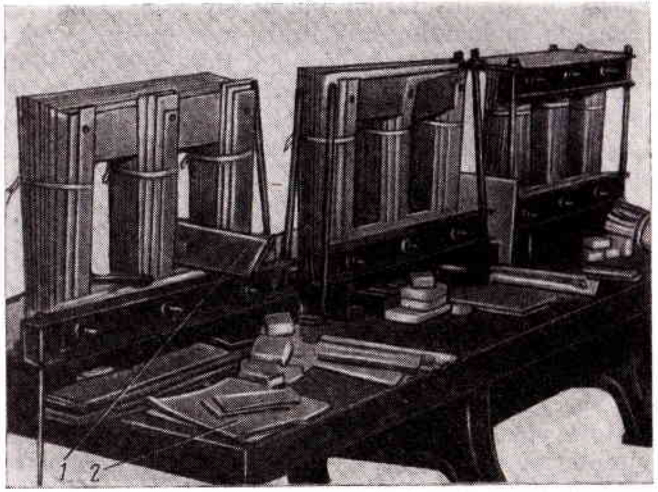


Fig. 70. Unblading the top yoke of a Size 1 transformer:
1—top yoke laminations; *2*—parts prepared for reblading

On reblading, the plates should go into the original positions, beginning with the last-removed plates which should be put on top of the stack on the cradle. The reblading operation should always be started at the place where the unblading operation was completed. Otherwise, the yoke may have to be rebladed again.

35. Preparation for the Assembly of the Core

After unblading, the core should be prepared for the placement of the insulation and of the coils. The preparation consists in banding the limbs as tightly as possible with lengths of tape passed through the holes for the yoke studs and inlining up the lamination packets in the limbs.

This is essential for two reasons. For one thing, if not lined up, the plates at the top ends of the limbs will make it impossible to centre the coils over the limbs. For another, even though it proves possible to centre a coil over its limb and to begin the placement, there may be a serious danger of cutting the inter-turn insulation by the sharp edges of the protruding plates inside the coils. This is dangerous because the damage cannot be detected after the coil has been put on its limb.

The core must be thoroughly inspected. On Size 3 transformers special attention must be paid to the oil duct in the bottom yoke and the limbs. It must be open for the free circulation of cooling oil. The edges of the plates in the bottom yoke and limbs should be free from dents or any other damage which may result in the short-circuiting of plates, which will inevitably entail increased heating and even a burn in the core.

Dents and nicks on the edges of the yoke and limb plates may be sometimes so large that the core will have to be unbladed and the defective plates replaced. In the case of slight damage it may be eliminated without unblading the core. It may happen sometimes that the edges of several plates in the bottom yoke are bent in the same direction by an accidental blow. To dress the plates, loosen the yoke a little, insert a steel flat chisel between the damaged plates, and straighten them. In the case of a damaged core-plate insulation, insert pieces of telephone-cable paper between the plates to restore the insulation.

After inspection and elimination of defects, clean dust from the core and blow it with a jet of compressed air.

36. Assembly of the Coils on Size 1 and 2 Transformers

Size 1 Transformers for up to 10 kV. Representative of this type will be a 100-kVA, 10-kV three-phase oil-immersed transformer whose core-coil assembly is not too difficult to put together. This size of transformer uses two-layer cylindrical coils on the L.V. side and multiple-layer cylindrical coils with ±5 per cent tappings on the H.V. side. The coils are wound on stiff synthetic-resin-bonded paper cylinders.

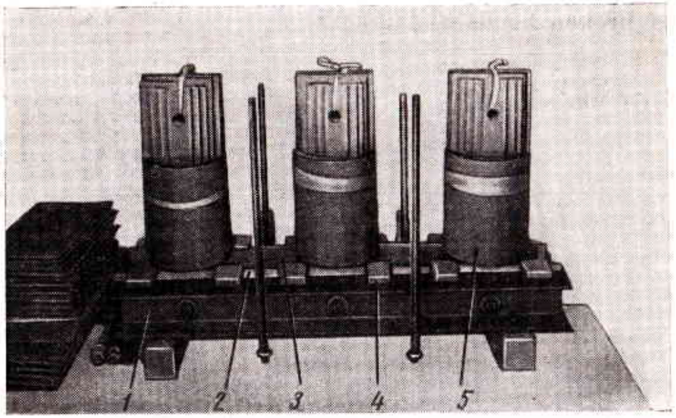


Fig. 71. Assembly of insulation on the core:

1—bottom yoke clamp; 2—pressboard sheet; 3—pressboard barriers; 4—wooden spacers; 5—pressboard wrap

The coil-end insulation in such transformers is built up of wooden spacers of simple shape. It also doubles as the yoke insulation. The spacers fit snugly under the steps of the top yoke and the coil end forming an even seating for the coils.

After a check on the coil for compliance with the order and design note, the temporary bands are removed from the coil. Then wooden spacers *4* (Fig. 71) are placed on the bottom yoke clamp *1*. The spacers should be secured on pressboard sheets *2* placed between the yoke and the yoke clamp. These sheets also lock the spacers in place. Next come two pressboard barriers *3* which should be also set up on the bottom yoke. The L.V. coil should be insulated from the limb with rectangular pressboard sheets 1 mm thick (or with twice as many sheets 0.5 mm thick) bent into semi-cylinders by hand.

Pressboard can be easily bent only along grain; when unbent, it will show no traces of bending. Across grain it gives broken bends and cracks.

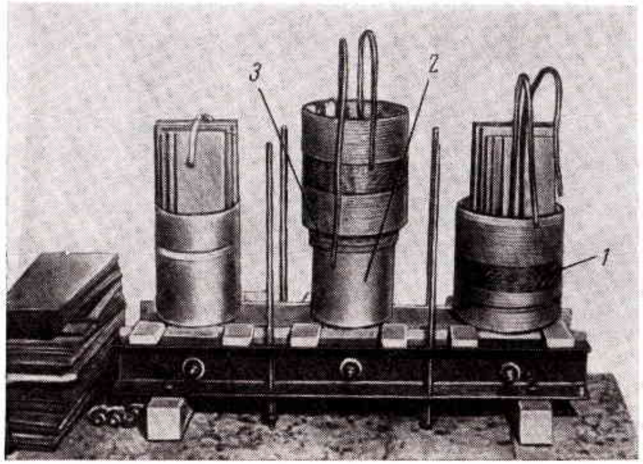


Fig. 72. Assembly of the L.V. winding on a Size 1 transformer:
1—L.V. winding; *2*—pressboard wrap; *3*—cotton cord

Two semi-cylinders put on each limb with an overlap and secured temporarily with a cotton string form a wrap *5*.

After the limbs have been thus insulated, the L.V. coils are put on them, starting with an outer limb, and the cotton string is removed from the respective wraps. The coil should fit onto the limb snugly (Fig. 72). Sometimes, the workman has to force it into the final position. However, he should never use a hammer for the purpose, since this will damage the winding insulation.

If the coil does not fit snugly on the limb, a thicker grade of pressboard should be taken for the wraps. If there is a marked difference in diameter between the limb and the coil, both diameters should be measured. Most often it will be found that the diameter of the limb (including the tolerance) is less than it should be. Then the core must be discarded.

The H.V. coils, too, should be placed on the limbs by hand, starting with an outer limb (Fig. 73). They should be assembled on the core according to drawings and the design note. The H.V. winding ends should be brought out on the core side opposite to that where the L.V. winding ends are taken out.

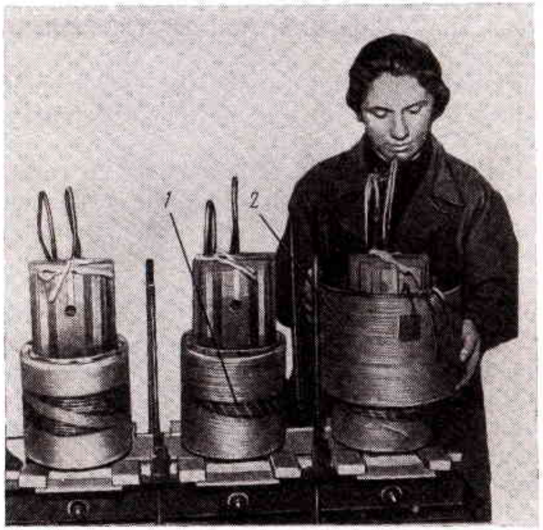


Fig. 73. Assembly of the H.V. winding on a Size 1 transformer:
1—L.V. winding; *2*—H.V. winding

The L.V. winding ends should be stripped of the wire insulation and of the varnish with which the coils are impregnated. As a rule, they are skinned with a gas torch and then scraped bright with a knife. The skinned L.V. winding ends should then be straightened, bent over a steel mandrel and insulated as specified in the drawing for a distance of 100 mm with cable-paper strips 20 mm wide. The paper strips should fit closely to the winding ends bent to drawing.

The paper strips should be applied to form a half-lap and to give the thickness specified in the drawing. The insulation thus applied should be then banded with linen-finished tape also applied half-lapped.

Both the bending and insulation of the L.V. winding ends is a critical operation, because the winding ends are run between the yoke clamp (which is earthed) and the H.V. coil end.

Size 2 Transformers for up to 10 kV. The coils of Size 2 transformers are assembled somewhat differently from the coils of Size 1 transformers.

Before the coils can be assembled on the core, the coil-end insulation should be placed on the yoke clamps. The coil-end insulation consists of four longitudinal and two transverse blocks (instead of small spacers used in Size 1 transformers).

The coil-end insulation is topped with the yoke insulation (see Fig. 40) which is a pressboard washer and pressboard blocks rivetted to it. The washer has holes for the L.V. winding ends. The yoke insulation is put on the limbs so that the cut-out in the washer for the L.V. winding ends be on the requisite side of the core.

After the yoke and coil-end insulation has been placed, the limbs are insulated from the L.V. coils with pressboard wraps (as described above).

In the case of Size 2 transformers, the L.V. and H.V. coils have to be lifted onto the core by crane. For lifting, the H.V. coil should be reliably secured with a cotton string *6* (Fig. 74), lest it should drop out.

There also is some difference in the winding end insulation. On multiple-layer coils, the ends of the L.V. winding adjacent to the H.V. winding are additionally insulated with a pressboard strip 0.5 mm thick and also with strips of cable paper as described above.

On continuous-disk or spiral windings and for voltages up to 10 kilovolt-amperes on the H.V. side, the winding ends are insulated with varnished cloth bias-cut into strips 25 to 30 mm wide. The strips of varnished cloth are applied to the winding ends half-lapped to obtain the thickness specified in the drawing, and are then banded with linen-finished tape also half-lapped.

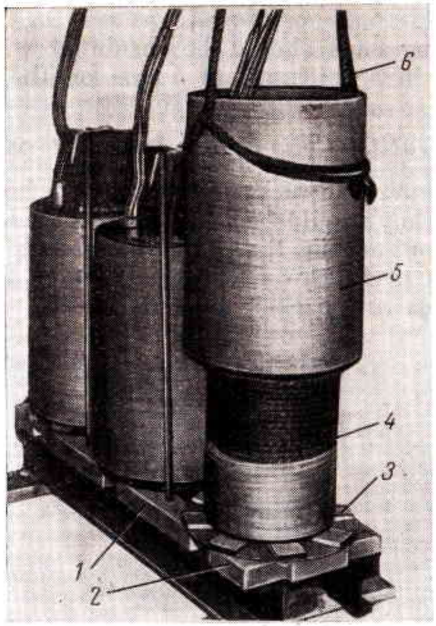


Fig. 74. Assembly of the H.V. winding on a Size 2 transformer

1—longitudinal block; *2*—transverse block; *3*—yoke insulation; *4*—L.V. winding; *5*—H.V. winding; *6*—cotton cord

Size 2 Transformers for up to 35 kV. The procedure is about the same as for Size 2 transformers. The H.V. winding is packed out with pressboard spacers which form horizontal (radial) ducts in the L.V. winding which may be of the spiral or continuous-disk type. The spacers also hold in place the insulating cylinder of the H.V. winding.

Special emphasis must be placed on the insulation of the L.V. winding ends. Before the insulation is applied, the winding ends must be properly bent and positioned. The clearance from the L.V. winding ends to the limb should be not less than 40 mm. If an L.V. winding end is improperly bent or insulated, it will be misplaced in the cut-out of the yoke clamp, the clearance to the yoke clamp and to the H.V. winding will be reduced, and the insulation may be punctured.

The winding ends should be insulated with varnished cloth to obtain a thickness of 4 mm on the side.

37. Packing Out the Coils in Size 1 and 2 Transformers

After the L.V. and H.V. windings have been assembled on the core, they should be packed out. The L.V. windings are packed out on the limbs by round bars and suitably shaped strips of beechwood placed next to the core. The H.V. windings are packed out on the L.V. windings by beechwood battens enclosed in pressboard boxes. The strips and battens are held in place by friction.

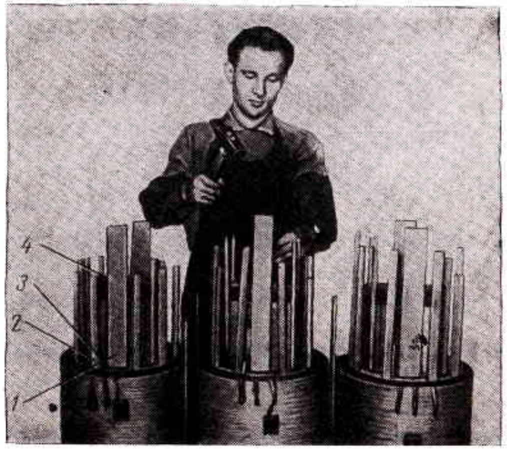


Fig. 75. Packing out the windings of a Size 2 transformer:

1—shaped beechwood packing strip; *2*—beechwood batten; *3*—pressboard box; *4*—round beechwood packing bar

The packing-out operation begins with the H.V. coils (Fig. 75). Two pressboard boxes *3* are placed between the L.V. coil and the H.V. cylinder, opposite each locking strip which hold in place the interturn spacers. Then beechwood battens *2* rubbed with paraffin wax are driven between the boxes to a depth of 30 mm.

Every other batten should be driven across the diameter from, rather than next to, the previous batten. If a batten slips in easily, a pressboard liner should be placed under it. Tightly fitting battens should be either replaced or reduced in thickness by planing as much as may be necessary.

Next come the L.V. coils. The packing out of the L.V. coils both locks them radially and applies additional pressure to the limbs. Use is made of round bars and shaped strips of beechwood (*4* and *1* in Fig. 75) driven between the limb steps and the pressboard cylinder of the H.V. winding.

Because of the waviness of the core laminations and the variations in the diameter of the winding and core, the diameter of the beechwood bars *4* specified in the drawing may prove sometimes greater or smaller than is actually required. Therefore, it will be good practice to try the bars first and to replace them with those of the correct diameter, if necessary.

The bars are then rubbed with paraffin wax and driven in by hand as far as they will go (to a depth of at least 30 mm). This done, the bars are further driven in with a hammer. In using a hammer, care must be taken to avoid heavy blows, as they may split the top end of a bar and it will have to be replaced. The round bars are driven in first, because they are of a smaller diameter and break easily. Also when the coil is first packed out with round bars, there is less danger that it will be made oval by the shaped packing strips.

After the bars and strips have gone in as far as the core, they are further driven in with vulcanized-fibre or wooden blocks put on their top end so as not to damage inadvertently the core plates or the winding end insulation. The beechwood bars and strips should run the whole length of the winding. Should the top end of a bar or strip be damaged, it should never be cut off, because some part of the winding will not be braced up against radial mechanical stresses occurring in transformer operation.

After the windings have been packed out, the top pressboard shields are installed between the top yoke and the winding, and also the interphase barriers, if any are specified in the drawing. The barriers are pressboard sheets up to 3 mm thick and have cut-outs at the ends which correspond with the steps of the yoke.

38. Assembly of the Coils on Size 3 Transformers for up to 35 kV

A much more complicated procedure is involved in the assembly of the coils on the core of Size 3 transformers for up to 35 kilovolts, and a more detailed description is therefore given. Size 3 transformers use either continuous-disk or spiral coils wound on stiff synthetic-resin-bonded paper cylinders.

Placement of the Bottom Coil-end and Yoke Insulation. Before the insulation can be installed, the H.V. and L.V. sides must first of all be identified. Proper identification is important, since otherwise all the windings may prove turned the other way round with respect to the core, making impossible the further assembly of the coils.

The core sides are identified by reference to the drawings of the core or lead assembly. Whether a yoke clamp belongs to the H.V. or the L.V. side is determined by the number and layout of holes in the clamp. The holes are intended to secure the beechwood cleats clamping and supporting the leads.

After the sides of the core have been identified, the coil-end insulation is installed. It may be made of either wood (for transformers up to 1,600 kVA in size) or tough pressboard. Wood is employed on a limited scale, because its compressive strength is too low to stand up to axial short-circuit stresses.

In the case of wood, the coil-end insulation, Fig. 41 (*a*), consists of beechwood blocks arranged both along and across the yoke clamps. The longitudinal blocks *1* have holes *2* for the tie-rods which hold the top and bottom yoke clamps together. The tie-rods also hold the blocks from displacement. The bottom transverse blocks *3* are held in place by studs welded to the yoke clamp flange; the top transverse blocks are locked in place by the nuts of the lifting rods.

When made of pressboard, the coil-end insulation consists of collars *4* to which spacers *5*, Fig. 41 (*b*), are rivetted from both sides. The collars are made up of segments and horseshoe shaped pieces. Their outer diameter should be a little greater than the outside diameter of the H.V. winding.

The spacers on the collars have the same width as the spacers on the washers of the yoke insulation. However, the spacers on either side of the collar differ in thickness. Those facing the yoke clamp flange form a smaller oil duct than facing yoke insulation washers. The L.V. winding ends are brought out through the ducts between the coil-end collar and the yoke-insulation washer.

Since the coil-end collars form a seating for the coils, the underside surfaces of the spacers should fit closely to the yoke-clamp flanges. In the case of any misalignment or displacement of the yoke clamps because of poor workmanship, the width of the spacers on the collars should be adjusted so as to obtain an even seating flush with the projecting part of the yoke.

The coil-end insulation is topped with the yoke insulation which is made of a pressboard washer and tough-pressboard spacers rivetted to it. The rivets are also made of pressboard. They should not run the whole thickness of the washers, as this would impair the electrical strength of the yoke insulation.

The yoke-insulation washer is sometimes made with cut-outs for the L.V. winding ends. As an alternative, it may be made composite, with a removable segment opposite the winding ends.

The yoke-insulation washer is put on the limb and is carefully aligned with the spacers of the coil-end collars so that the cut-out in the washer is on the requisite side of the core and the spacers are aligned vertically with the inter-turn spacers. The offset of the spacers due to inaccuracy in manufacture should not exceed two or three millimetres. In the case of a greater offset the spacers will fail to give sufficient support to the coils. Also, the installation of the coils on the core will be handicapped.

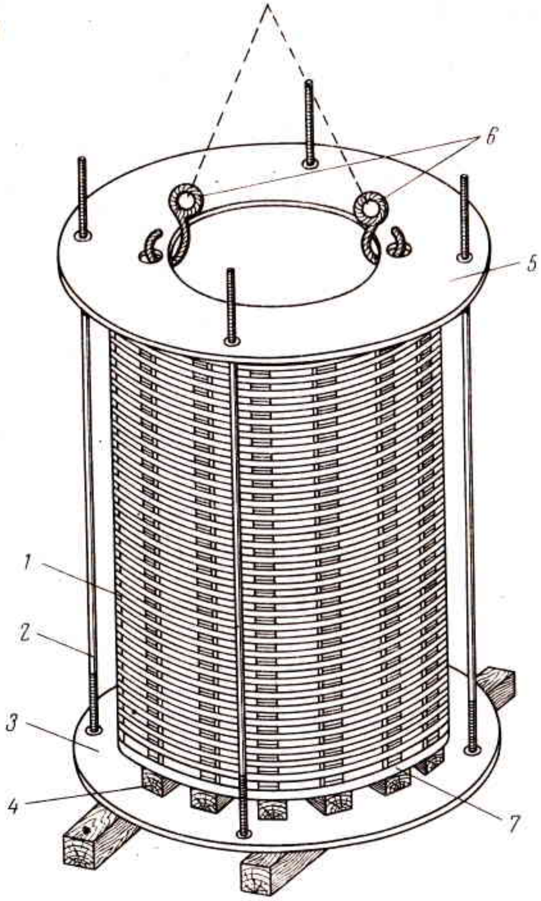


Fig. 76. A transformer winding before removal of the top end ring after unclamping:

1—winding; *2*—tie-rod; *3*—bottom pressure or end ring; *4*—beechwood block; *5*—top pressure or end ring; *6*—lifting hooks; *7*—pressboard ring

After the yoke insulation has been installed, the pressboard shields covering the yoke are mounted.

The next operation on 2,500-kVA transformers is to mount on the limbs wooden filling strips to position the coils on the core. The strips should have holes for the nuts of the core bolts. The filling strips should run the whole length of the limbs, making them nearly circular in cross section and enhancing their resistance to radial mechanical stresses.

The bottom ends of the strips fit into the gap between the limbs and the yoke-insulation washers and should fit closely to the surface of the limbs. If, because of the waviness of the limbs, this requirement is not met, the strips should be made to fit to the surface of the limbs. Otherwise, the limb diameter will increase, and there will be some difficulty in putting the coils on the core. The filling strips are then banded temporarily with herring-bone tape.

Checking the Coils for Axial Dimensions. The coils come in for assembly clamped down to the axial dimension specified in the drawing. In the winding division, the coils are pressed and clamped up between two steel pressure or end rings *3* and *5* which are held together by steel tie-rods *2* (Fig. 76). Before pressure is applied, beechwood blocks *4* of equal height are placed between the end rings and the coils. This is done so that the locking strips, which are equal in height to the coil unpressed and stick out of the coil as the pressure is built up, will not run up against the end rings, damaging the coil.

The clamped-up coils are handled with the aid of a specially designed fixture (Fig. 77) which consists of a steel eye *1* attached to steel wire-ropes *2* terminating in grips *3*. The eye *1* is put on the lifting hook of a crane, and the grips are applied to the top end ring *5* so that they are spaced 120° apart.

The compressed coil has the same axial dimension as it should have after it is assembled and compressed on the core. Therefore, this dimension should be checked prior to the assembly. The dimension is indicated on the pressboard tag attached to the winding ends. The tag also gives the number of the order and of the winding instruction card. The tag should bear the signature and seal of the quality inspector.

Testing the Coils for Inter-turn Short and Open Circuits. The coils come in for assembly varnish-impregnated and baked. Therefore, the winding ends should be stripped not only of their own insulation but also of the varnish. The winding ends are usually skinned with a gas torch followed by a knife and sand paper.

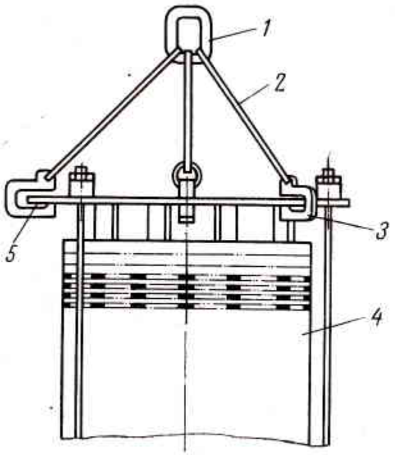


Fig. 77. Lifting tackle for a winding clamped between the end rings:
1—eye; *2*—steel wire-rope; *3*—grip; *4*—winding; *5*—end ring

Continuous-disk windings wound with multiple parallel conductors and also spiral windings with group and general transpositions should be tested for open and short circuits in the individual conductors before the coils are unclamped. Spiral coils with distributed transposition are tested only for open circuits in the parallel conductors.

The short-circuit test should be carried out prior to unclamping, because, when unclamped, the multiple conductors may change their relative position and the short circuit, if there is any, will be cleared to reappear on reclamping.

The short-circuit test is accomplished by means of a megohmmeter. The ends of the multiple conductors where they leave the coil are separated, the lead *3* (see Fig. 78, *a*) of the megohmmeter is connected to one of the lower ends *1'* through *5'* of the multiple conductors, and the other megohmmeter lead *2* is brought in contact in turn with the top ends *1* through *5*.

The megohmmeter should indicate a short circuit only once—when both of its leads are connected to the same conductor. If the instrument indicates a short circuit more than once, there is a short circuit between some of the multiple conductors. The short circuit should be located at she testing station, and cleared before the coil is to be assembled on the core.

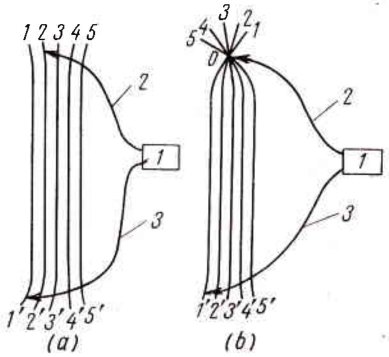


Fig. 78. Testing L.V. windings:
a—for internal short circuits; *b*—for continuity; *1*—megohmmeter; *2* and *3*—megohmmeter leads

For an open-circuit test, Fig. 78 (*b*), the skinned top ends *1* through *5* of the multiple conductors should be bunched together at *0*, while the lower ends *1'* through *5'* are left separated. The megohmmeter lead *2* is connected to the common termination *0*, and the other megohmmeter lead *3* is brought in contact in turn with each of the lower ends *1'* through *5'*. The megohmmeter should indicate a short circuit for all the conductors. If the instrument reads a high resistance for one of the conductors, the latter is open-circuited.

Preparation for Coil Assembly. After the open- and short-circuit tests, the L.V. winding is unclamped. To do this, the nuts on the tie-rods *2* (Fig. 76) are backed in turn, then run off completely, and the top end ring *5* is lifted off the winding by crane.

Then the beechwood blocks are removed from the pressboard ring *7*, and the top ends of the pressboard locking strips are trimmed off. The locking strips should be trimmed off at the mid-height of the pressboard ring and not level with its top surface. This is done because even a well-dried winding will shrink somewhat axially after the drying of the core-coil assembly. If the locking strips were trimmed off level with the top surface of the pressboard ring, they would run up against the insulation parts on top of the winding after drying, making the clamping of the winding impossible. The bottom ends of the locking strips are trimmed off to within 5 or 6 mm of the top surface of the bottom pressboard ring immediately before the winding is assembled on the core.

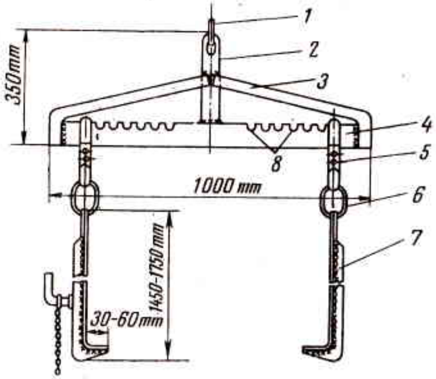


Fig. 79. Two-bar spread frame for coil assembly:

1—lifting eye; *2*—vertical link; *3*—frame; *4*—bar; *5*—hook; *6*—ring; *7*—grip; *8*—notches

Assembly of the Windings on the Core. The windings are assembled on the core by the use of a specially designed fixture which consists of a spread frame and grips. The size and design of the fixture vary with the weight and size of windings. For the windings of Size 3 transformers (up to 600 mm in diameter), a two-bar fixture is usually employed (Fig. 79).

The spread frame is of simple welded construction, consisting of a brace *3* and spread-bars *4*. The thickness of the spread-bars varies with the load-lifting capacity of the fixture and does not usually exceed 20 mm. Both spread-bars have an equal number of notches *8* which receive the hooks *5* of the grips *7*. The grips are spaced an equal number of notches from the middle of the frame. By varying this spacing, it is possible to adjust the fixture for windings of different diameters. The vertical link *2* terminates in an eye *1* with which the fixture is suspended from the hook of a crane.

The usual practice is to have several sizes of grips for the same fixture in the assembly shop, each size being designed for a definite winding size and a definite load. The grips also differ in the size of the supporting arms (30 or 60 mm) and in length (1,450 or 1,750 mm).

Two identical grips should be chosen so that the winding can be lowered on the grips as far as the bottom yoke-insulation washer, the width of the arms should not exceed the radial depth of the winding (the difference between the outside and inside diameters of the winding), while supporting the pressboard ring over at least three-quarters of its width.

The grips should be applied to the bottom pressboard ring of the L.V. winding equally spaced all the way round the circumference and in line with the pressboard inter-turn spacers. To make room for them, several wooden blocks are knocked out from between the winding and the bottom steel end ring. The grips should be placed so that they will not find themselves between the core limbs; that would make their removal quite a problem.

The grips (Fig. 80) are then secured near the top and bottom of the winding with a cotton cord 12 mm in diameter. If not properly secured, the grips may move apart on lifting, letting go of the winding. Secured with the cord, the winding is then lifted off the steel end ring, and the locking strips are trimmed within 5 or 6 mm of the bottom pressboard ring.

The winding is then examined thoroughly for damaged insulation on the outer surface of the turns, foreign objects left in the winding, overflows of varnish between the coils, and misaligned locking strips. It is also important to make sure that the intercoil connections are properly made and the ride-ups or run-overs are squeezed down to the winding.

Thus examined, the winding is lifted by crane over the core so that its axis is in line with that of the limb on which it is to go (Fig. 80). The winding is slowly lowered and steered by hand so that the spacers on the coil-end collars and the yoke-insulation washers are in line with the inter-turn spacers, and the bottom ends of the winding fit between the coil-end collar and the yoke-insulation washers as indicated in the drawing. The alignment of the winding should be checked with a plumb bob.

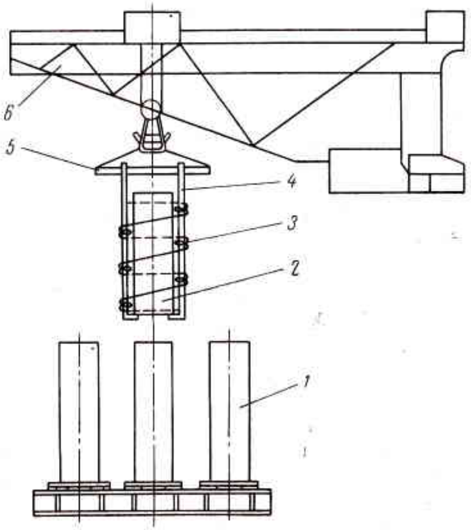


Fig. 80. Assembly of an L.V. winding on the transformer core:
1—core; *2*—winding; *3*—cotton cord; *4*—lifting grip; *5*—two-bar spread frame; *6*—crane

If the winding happens to swerve from the desired direction, it should be lifted off again without removing it completely from the limb and turned so that the inter-turn spacer locking strips are in line with the spacers on the coil-end collar and the yoke-insulation washer.

Usually, the L.V. winding is not lowered all the way down. It is stopped within 80 to 100 mm of the yoke-insulation washer and propped up by wooden blocks. This is done in order that the grips of the lifting fixture can be removed and the bottom ends of the winding can be bent and insulated without obstruction. The multiple conductors of the L.V. winding should be straightened, bent on the flat, laid parallel to each other, and bent to the drawing.

The ends of the L.V. winding are insulated as described earlier. The top ends of the L.V. winding are insulated after the H.V. winding is assembled on the core.

The bottom ends of the L.V. winding being insulated, the temporary blocks are knocked out from beneath it. Sometimes, the weight of the winding may prove insufficient to make it go all the way down. If this happens, an additional weight must be applied to it.

After the L.V. winding has been placed on the limb *3* (Fig. 81), it should be packed out. Use is made of round beechwood bars *1* and *2*, and of shaped beechwood strips *4*. A detailed description of the packing-out operation will be found in Sec. 37.

Then the L.V. winding *6* is blown with compressed air and the H.V. winding *8* is put on the limb, after it has been inspected and prepared as the L.V. winding. The H.V. winding is lowered onto the limb by the use of the same lifting fixture, with its grips applied to the winding in exactly the same manner. Again, it must be made sure that the coil spacers *16* are in line with the spacers on the coil-end collar and the yoke-insulation washer. The voltage-control tappings should be arranged as shown in the drawing.

If the L.V. winding is of either the continuous-disk or the spiral type, its spacers forming radial ducts are used to brace the insulating cylinder *7* of the H.V. winding.

The L.V. and H.V. windings of each phase should be separately driven down with a dead-weight. To do this, blocks are set up on the winding from two sides, and a weight of 3 tons is lowered by crane on the blocks. The dead-weight should be lowered so that its centre of gravity is in line with the axes of the windings. The procedure is illustrated in Fig. 82.

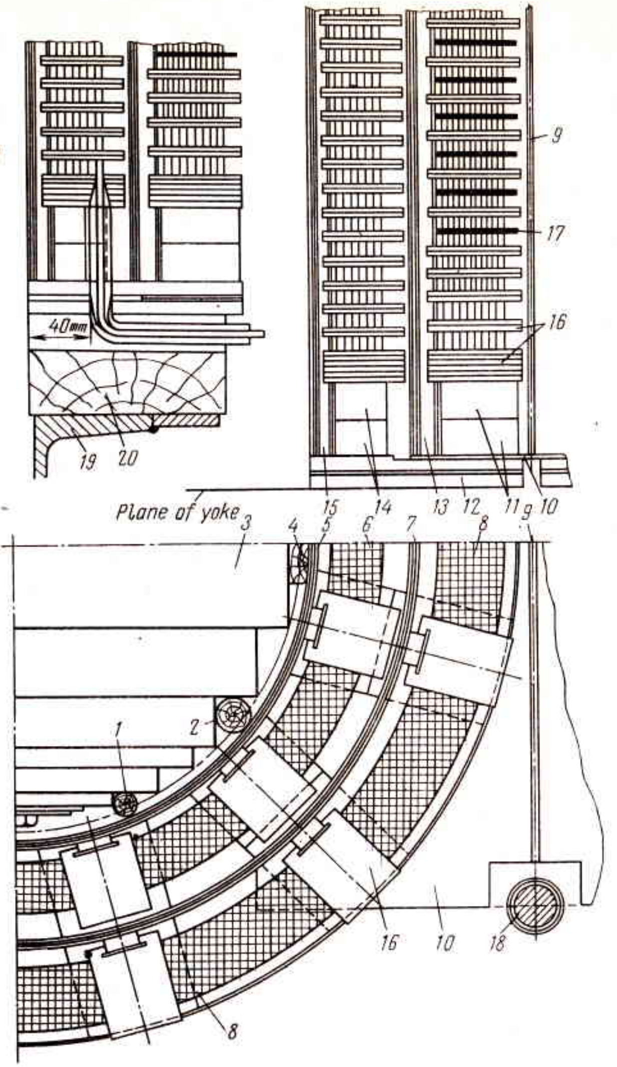


Fig. 81. Assembly of a winding on a Size 3 transformer:

1 and *2*—round beechwood filling bars; *3*—core; *4*—beechwood packing strip; *5*—synthetic-resin-bonded paper cylinder of L.V. winding; *6*—continuous-disk L.V. winding; *7*—synthetic-resin-bonded paper cylinder of H.V. winding; *8*—continuous-disk H.V. winding; *9*—interphase barrier; *10*—pressboard yoke shield; *11*—pressboard pressure rings of H.V. winding; *12*—yoke insulation; *13*—pressboard locking strip of H.V. winding; *14*—pressboard pressure rings of L.V. winding; *15*—pressboard locking strip of L.V. winding; *16*—pressboard turn spacers of H.V. winding; *17*—pressboard washer; *18*—steel tie-rod insulated with synthetic-resin-bonded paper tube; *19*—yoke clamp; *20*—coil-end insulation

For the easier reblading of the top yoke, the windings should be clamped down 4 or 5 mm below their axial dimensions specified in the drawing, because, when relieved of the pressure, the windings will somewhat increase in length.

The insulation between the winding and the top yoke is similar to that between the winding and the bottom yoke (Fig. 81), except that the insulation components are stacked up in reverse order. Next the interphase barriers *9* are set up and banded by linen-finished tape to the tie-rods *18*. After that, the pressboard shields *10* are put on the yoke, and the top yoke washer *12* and the coil-end collar *20* are installed.

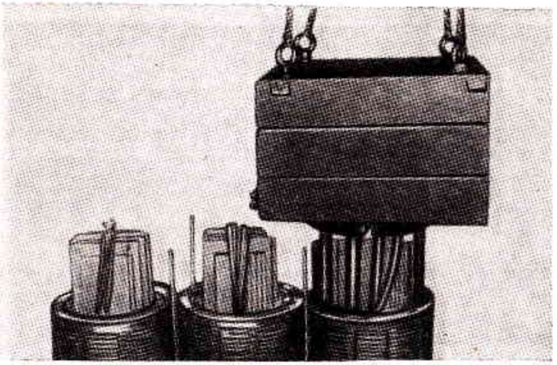


Fig. 82. Applying a weight to windings

39. Reblading the Top Yoke

The reblading of the top yoke is one of the most critical operations in the assembly of the core-coil unit. Misplaced laminations, excessive gaps between them, overlapping joints and damaged insulation will all affect the performance of the transformer, especially its exciting current.

The main rule for reblading the top yoke is the proper interleaving of the limb and yoke plates. They should be stacked up so that every alternate packet of yoke laminations interleaves with two packets of limb laminations, and adjacent packets of yoke laminations come abutting with them.

The yoke laminations interleaving with the limb laminations in the outer phases (*A* and *C*) are usually referred to as *corners* while the yoke plates placed between the limb plates of the middle phase (*b*) are termed *middlings*.

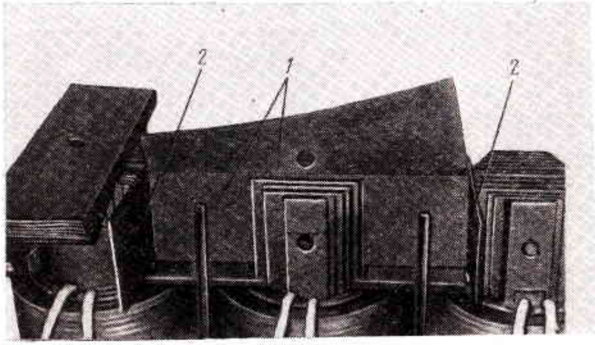


Fig. 83. Reblading of the top yoke:
1—middle lamination packet of the middle limb; *2*—temporary aligning plate

In Size 1 and 2 transformers, the yoke is rebladed, starting with the middle limb and stacking up the yoke plates in packets. The number of plates in a packet is specified in the drawing. Usually, there are three laminations in a packet. The packets are placed between the projecting vertical plates of the limb.

For proper alignment of the yoke laminations in the middle limb, aligning plates *2* (Fig. 83) should be set up along the inside faces of the outer limbs. The plates of the top yoke with paper insulation should be inserted with the unpapered side outwards, starting at the middle of the middle limb.

After the middlings have been rebladed, the temporary aligning plates *2* are removed, and the corner plates are inserted. The same procedure is followed in stacking up the other packets, i.e., the middle (longer) laminations are installed first, then the corners.

The corners should be installed, starting on the outer edge of the limb, so that they are fully abutting with the top edges of the respective shorter plates of the outer limb and fit, at the same time, snugly to the side edges of the plates in the middle limb. It is essential that every corner plate should make a butt joint with the respective projecting vertical plate of the limb. Failure to observe this rule will leave the yoke with gaps, and everything will have to be redone.

In reblading the yoke, the following points should be borne in mind. Firstly, the corner plates of the yoke should be interleaved in such a way that their ends do not extend beyond the limb plates. Secondly, the middle plates should be so arranged as to permit a check on their position with a steel drift inserted through the holes in the yoke and limb.

The yoke and limb plates should neither overlap nor form gaps. In both cases, there will be an increased opposition to the magnetic flux, and the transformer will require a heavier exciting current.

While interleaving, the yoke plates should be made to abutt with the limb plates whenever possible. Most often, however, this has to be done with a hammer and a vulcanized-fibre pad after the yoke has been completely rebladed. At the same time, the plates projecting at the yoke ends are hammered in so as to reduce the gaps between the corner and successive plates of the yoke. The vulcanized-fibre pad should be placed along and not across the plates. Instead of vulcanized fibre, use may be made of pieces of copper bars 12 to 15 mm thick. In all cases the plates must be guarded against direct hammer blows.

The top yokes of Size 3 transformers are usually rebladed concurrently from two sides. It is important to begin the reblading from where the last plate was removed on unblading (the place should be marked with a piece of herringbone tape). If the reblading is commenced at random, there may be too many plates on one side and a few plates missing on the other. As a result, some of the plates will be misplaced, and the yoke will have to be taken apart and rebladed again.

While interleaving the top yoke, a constant check must be kept on the alignment of the holes in the plates for the yoke studs. If necessary, the misaligned plates should be lined up with the aid of a steel drift inserted into the holes. This is an important operation, since it ensures the proper position of the middle plates in the yoke. Even a single plate misaligned with respect to the hole in the yoke will not let in the synthetic-resin-bonded paper tube which should be free to go in. As more plates are put back into the yoke and lined up, they should be clamped with U-cramps (Fig. 84) arranged in a staggered pattern.

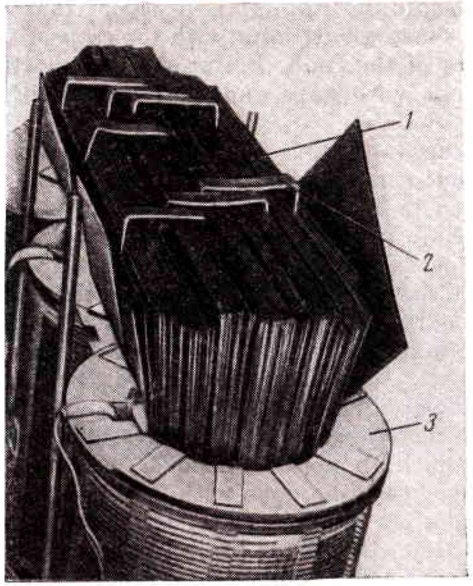


Fig. 84. Reblading of the top yoke in a Size 3 transformer:
1—top yoke laminations; 2—U-cramps; 3—yoke insulation

40. Clamping Up the Core-coil Assembly

Preparation for Clamping Up. The clamping up of the core-coil assembly is the last, very important and most labour-consuming operation in the first stage of transformer assembly. Before the top yoke is finally compressed and clamped up, it is necessary to run down the yoke plates against the limbs where this could not be done during the reblading.

In the case of Size 1 and 2 transformers, the first step is to mount the top yoke clamps. The top yoke clamps should be insulated from the yoke with pressboard sheets 3 mm thick. In Size 3 transformers, an oil duct is obtained between the yoke and the top yoke clamp by inserting a pressboard sheet to which are rivetted vertical spacers also of pressboard.

Clamping Up of the Core-coil Unit in Size 1 and 2 Transformers. The top yoke clamp, with the tie-rods passing through it, is placed on the wooden or pressboard spacers arranged on top of the yoke, and pressure is uniformly applied to the winding by tightening the nuts on the tie-rods *3* (Fig. 85).

The top yoke laminations not lined up during the interleaving operation are driven down with a hammer through a vulcanized-fibre pad until they run against the limb plates. The yoke plates should be driven down uniformly, avoiding dents or bends on the individual laminations (Fig. 86). The vulcanized-fibre pad *2* should be placed with its narrow side on the projecting laminations and struck with a sledge-hammer *3* at the ends of each lamination in turn, then at the middle and again at the ends until the laminations come in contact with the limb plates. The gap at the joint should be not more than 1 mm.

At the same time, the sides of the core are made even by the same procedure. Where plates show up in the holes of the top yoke, they are lined up with a steel tapered drift. After the holes (at *10* in Fig. 87) have been lined up, synthetic-resin-bonded paper tubes *7* are inserted, and into the tubes are slipped steel yoke studs *5* carrying steel (*6*) and pressboard (*3*) washers and nuts *4* on one end. Similar washers are placed on the other end of the studs emerging from the holes, and nuts are run onto them.

The earthing connection of the core should be installed on the L.V. side. This is a tinned copper ribbon 30 mm wide and 0.3 mm thick. One end of the ribbon is clamped between the yoke plates to a depth of about 40 mm and

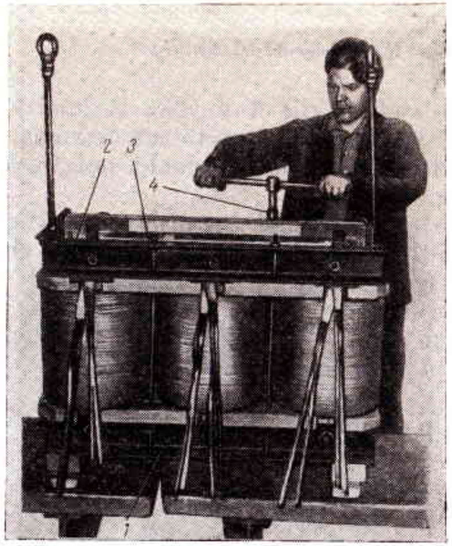


Fig. 85. Clamping the windings with the tie-rods:
1—bottom yoke clamp; *2*—top yoke clamp; *3*—tie-rod; *4*—box spanner

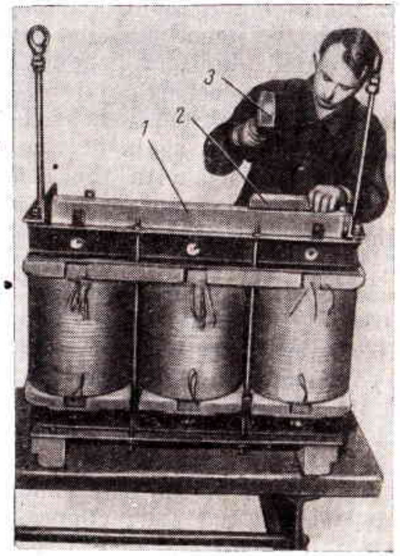


Fig. 86. Driving down the laminations of the top yoke:
1—top yoke; *2*—vulcanized-fibre pad; *3*—sledge-hammer

within 10 mm of the edge of the yoke. The other end of the ribbon is made to fit snugly to the inside surface of the web of the yoke clamp.

Then the top yoke is finally clamped up, and the No. of the transformer is stamped on the left-hand end of the top yoke clamp on the L.V. side.

Clamping Up of the Core-coil Assembly in Size 3 Transformers. The clamping up of the core-coil assembly in Size 3 transformers is a more complicated procedure and calls for a more detailed discussion.

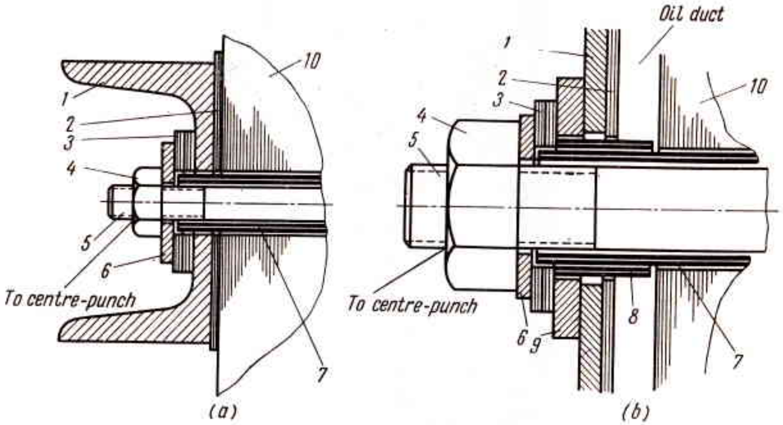


Fig. 87. Details of the clamping structure of a transformer yoke:
a—Size 1 and 2; *b*—Size 3; *1*—yoke clamp; *2*—pressboard sheet; *3*—pressboard washer; *4*—steel nut; *5*—steel stud; *6*—steel washer; *7*—synthetic-resin-bonded paper tube; *8*—synthetic-resin-bonded paper bushing; *9*—steel plate; *10*—yoke

Since each top yoke clamp belongs to a particular side of a transformer, it is essential to identify where it belongs before installation. The top yoke clamps are mounted by crane. The clamp is lifted by the lifting eyes and is placed on the coil-end collar (which may be of wood or pressboard) so that the tie-rods pass through its holes. Using a steel tapered drift inserted into the central hole, the yoke clamp is aligned with the top yoke and is then clamped to it with a U-cramp so that one tyne of the cramp catches at the top flange of the clamp and the other is inserted between the yoke laminations.

With one of the yoke clamps thus secured, the crane can now be used to handle the other in a similar manner. With the other clamp still suspended from the crane, temporary studs *1* (Fig. 88) are inserted into the outer holes of the clamps, and the clamps are tightened up. As the pressure on the clamps increases, the U-cramps are removed one by one from the yoke, and the yoke plates are now held together by the top yoke clamps.

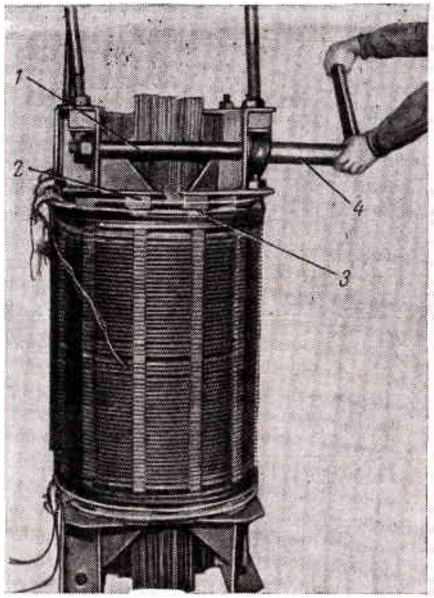


Fig. 88. Pretightening of the yoke clamps:
1—temporary yoke stud; *2*—coil-end insulation; *3*—yoke insulation; *4*—box spanner

There is a simple method for removing a U-cramp from the yoke: another U-cramp is inserted as shown in Fig. 89, and its tyne lying flat on the yoke is used as a lever in order to pull out the first cramp.

Then the tie-rods are gradually tightened so as to exert a uniform pressure on the windings. As the pressure increases, the sides of the core are made even and the protruding laminations are driven down, starting at the outer limbs.

The top yoke laminations should be driven down with a sledge-hammer and a vulcanized-fibre pad, taking care not to indent or bend some of the laminations. The laminations should be driven down until all of them are flush with the corresponding plates in the limbs and all the holes in the top yoke laminations are lined up.

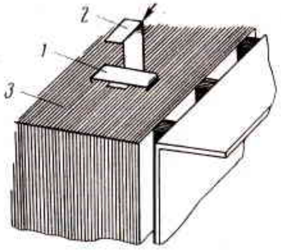


Fig. 89. Removing U-cramps prior to clamping up the top yoke:
1 and *2*—U-cramps; *3*—top yoke

As stated above, the gap at the joints should not exceed 1 mm. The holes partly closed by top yoke laminations should be lined up with a steel tapered drift. At the same time, the windings are compressed to the requisite axial length. If, however, the windings are not sufficiently compressed and the holes in the top yoke and top yoke clamps for the yoke studs fail to align, the yoke clamps have to be pulled down. In most cases this is done by applying a weight of 12 to 14 tons to the top yoke clamps.

The axial length given in the drawing is specified for a winding so compressed that none of its sections can move axially. An increased axial length is an indication that the winding is undercompressed. This is dangerous for the following reason. The short circuits (partial or complete) which may occur in a transformer give rise to appreciable voltage surges and, as a consequence, to considerable mechanical stresses. In an undercompressed winding, these voltage surges may dislodge individual turns or sections, destroying the insulation and the parts that give the winding the requisite mechanical strength.

Then synthetic-resin-bonded paper tubes are inserted into the holes in the top yoke clamps and yoke, and into them are slipped the yoke studs fitted with synthetic-resin-bonded bushings, steel and insulating washers and nuts on one end, Fig. 87 (*b*). Similar bushings, washers and nuts are also fitted on the other end of the studs emerging from the holes on the other side of the yoke. The nuts are then tightened with a box spanner to apply a uniform pressure to the top yoke.

The top yoke clamps are earthed with two tinned copper ribbons, each 120 mm long, 30 mm wide and 0.3 mm thick, fitted on the L.V. side. One ribbon is anchored between the top yoke laminations to a depth of 70 to 75 mm and within about 10 mm of the end of the yoke. The other ribbon is made to fit snugly to the inside surface of the yoke-clamp web. After the preliminary test of the core-coil assembly, both earthing ribbons are joined together with a soft solder (Grade ПОС-40).

The clamping-up operation may be taken as completed when the top yoke clamps on either side of the core are tightened down and fit snugly to the top yoke and the coil-end collar. Then the temporary studs may be removed, and the No. of the transformer is stamped on the top yoke clamp on the L.V. side.

Sometimes the insulation may swell because the windings have not been properly dried or have been kept in storage prior to assembly for a long time. If this occurs, neither the windings nor the top yoke may be clamped up. Before this may be done, the core and the windings should be dried exactly as the core-coil assembly would. After drying, the laminations are driven down and the core-coil structure is finally clamped up.

41. Assembly of the Core-coil Units of the Type ATMK-100/0.5 Moving-coil Voltage Regulator

The characteristic feature of the ATMK-100/0.5 regulator is a short-circuited coil, of transformer type, moving up and down each limb of the laminated iron core. Hence the name "moving-coil" voltage regulator.

The moving-coil regulator is built in general on the same lines as ordinary static transformers. The laminated iron core, coils, insulation, structural work, and general assembly are in accordance with standard transformer practice.

Yet, the assembly of the core-coil units (of which there are three, one per phase) differs from the procedure described for Size 1 through 3 transformers.

The magnetic circuit of the regulator consists of three two-legged single-phase cores. Each core carries two fixed coils A and B, and a short-circuited coil P free to move up and down the limb over the fixed coils. The core-coil units are set up between the top and bottom plates of the operating mechanism. The two plates are clamped together by three vertical steel tie-rods.

The top yoke is unclamped and unbladed exactly as in the case of Size 1 and 2 transformers. The middle laminations of the top yoke are banded tightly with cotton tape passed through the yoke stud holes. Before the coils are assembled on the core, the latter should be cleaned of dust, blown with compressed air and identified for the L.V. and H.V. sides. The terminal side is that which has holes in both the top and bottom yoke clamps.

The coils are placed on the core to the drawing of Fig. 90. The winding ends at the top and bottom yokes are bent to the requisite shape and insulated before the windings are put on the limbs. Then the yoke-insulation washer *3* is placed on the bottom yoke. The fixed coils are insulated from the limbs with rectangular pressboard sheets *2* and *5*, with a thickness of 1 mm (or with twice as many sheets 0.5 mm thick), which are bent into semi-cylinders by hand. The two semi-cylinders half-lapped around the respective limb and secured temporarily with cotton cord make a pressboard wrap.

The fixed coil A (*4*) is placed over the wrap by hand, with the winding ends laid precisely along the axis of the limb. Having made sure that the coil has been placed correctly, it is packed out with beechwood strips *1*. Before they can be used, the strips should be matched for thickness and rubbed with paraffin wax. The strips should be driven in

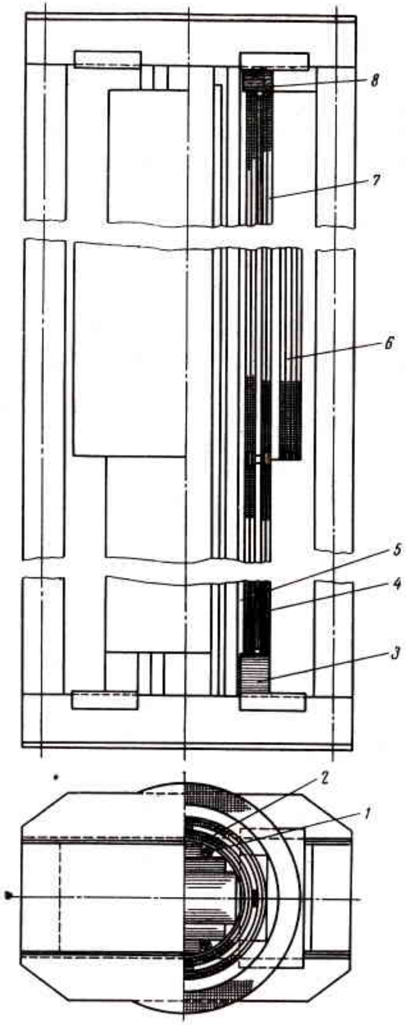


Fig. 90. Assembly of a phase of moving-coil voltage regulator:

1—beechwood bar; *2*—pressboard sheet, 1 × 230 × 490 mm; *3*—bottom yoke insulation; *4*—coil *A*; *5*—pressboard sheet, 1 × 230 × 570 mm; *6*—moving coil *P*; *7*—coil *B*; *8*—top yoke insulation

first by hand to a depth of 30 to 40 mm and then with a sledge-hammer, placing a vulcanized-fibre pad on the strip ends.

Because of the high quality of the winding-end insulation, the other fixed coil *B* (*7*) may be placed closely adjacent to the coil *A*. The wraps, the coil *B* and the packing strips are all mounted exactly as for the coil *A*.

Then the movable short-circuited coil *P* (*6*) is placed over the fixed coils *A* and *B* by hand, and the insulating washer *8* of the top yoke is applied. The movable coil is fastened after the three core-coil units of the regulator are set up in the operating-mechanism frame.

The top yoke is rebladed as described in Sec. 39, and the yoke clamps (angle irons) are mounted on it. Then the yoke studs are inserted, and initial pressure is applied to the yoke. The top yoke laminations which have been rebladed are driven down with a hammer or a sledge-hammer striking over a vulcanized-fibre pad until they run up against the limb laminations. At the same time, the sides of the core are made even.

If the coils are to be compressed properly, the assembled core-coil units of the regulator should be vacuum-dried (see Chapter 6) before they are mounted into the operating-mechanism frame and the connections are soldered. After drying, the yoke laminations are finally driven down, the synthetic-resin-bonded paper tubes and the yoke studs are inserted, and the top yoke is given a final clamp-up.

To prevent the nuts on the yoke studs from working loose in service, the nuts on the bolts should be centre-punched. Before the core-coil units are mounted into the operating-mechanism frame, the insulation of the yoke bolts should be tested with a megohmmeter.

Mounting of the Core-coil Units into the Operating-mechanism Frame. The operating mechanism (Fig. 91) moves the short-circuited coils *P* up and down the core limbs.

The top plate *1* of the operating-mechanism frame (which also serves as the cover of the regulator tank) mounts a reduction gear unit *6*, a 0.27-kW three-phase 220/380-V motor, and the associated switchgear. The reduction gear unit transmits rotation of the motor to a square-threaded vertical shaft *11*.

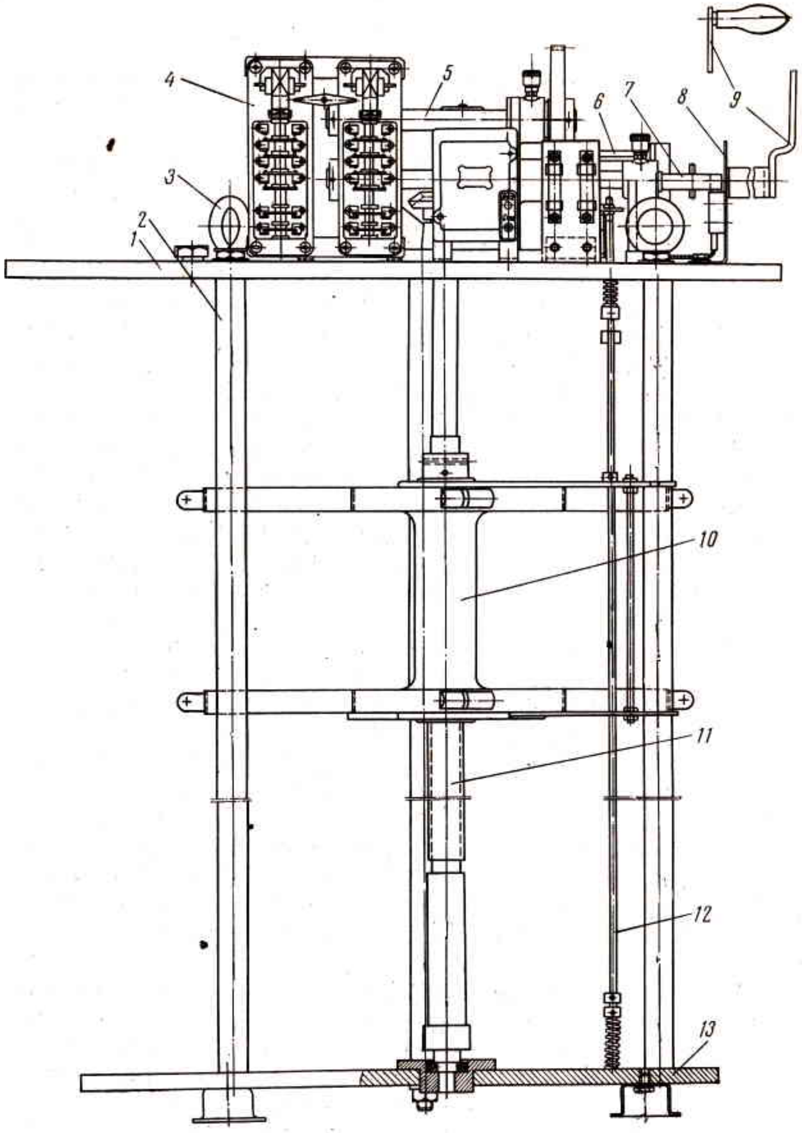


Fig. 91. Operating mechanism of a moving-coil voltage regulator:

1—top plate of operating-mechanism frame; *2*—tie-rod; *3*—lifting eye; *4*—starter; *5*—electric motor; *6*—reduction gear unit; *7*—shaft; *8*—interlocking switch; *9*—crank; *10*—moving-coil frame; *11*—drive shaft; *12*—link; *13*—bottom plate of operating-mechanism frame

The shaft both supports and operates a non-magnetic frame *10* which carries the short-circuited coils. The operating mechanism can be controlled both remotely and locally, by means of a crank *9*.

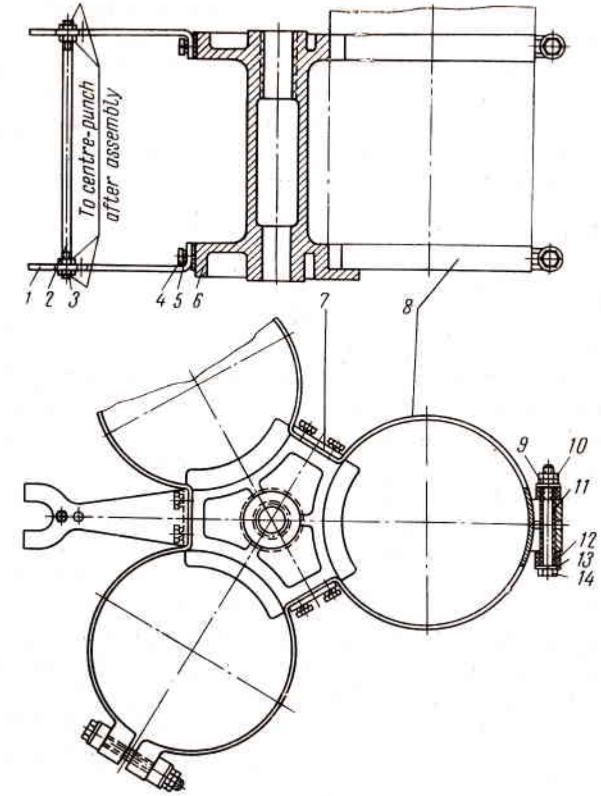


Fig. 92. Moving-coil frame of a moving-coil voltage regulator:

1—steel bracket; *2*—steel stud; *3* and *9*—steel nuts; *4* and *14*—steel bolts; *5*—spring washer; *6*—special nut; *7*—steel plate; *8*—clip; *10*—low nut; *11*—synthetic-resin-bonded tube; *12*—paper-base laminate washer; *13*—steel washer

For installation of the core-coil units, the crank is rotated clockwise to move the frame *10* into the topmost position and the parts (*9* to *14* in Fig. 92) are removed from each of the clips *8*. The ends of the clips should be bent so that the distance between them is greater than the outside diameter of the fixed coils.

Then the assembled core-coil unit of phase *B* is lifted with an overhead travelling crane slightly above the bottom plate *13* of the operating mechanism (Fig. 91), so that the core touches the top plate *1*. The bottom portion of the core is inclined a little towards the mechanism and is lowered into the operating-mechanism frame. The holes in the bottom yoke clamp of the phase *B* core are lined up with the holes in the bottom plate by means of a drift and two bolts are inserted in turn. When mounting the core-coil assembly, make sure that the outer limbs of the core and the outer surface of the moving coil pass well clear of the clip ends.

Next the crank *9* is rotated counter-clockwise to move the frame *10* into the lowermost position, and the clip ends are bent to a circle with a diameter approximately equal to that of the moving coil *P*.

The core-coil unit of each phase is clamped inside the operating-mechanism frame by means of the square steel washers provided between the top yoke clamps and the top plate of the frame. The top yoke clamps are fastened to the frame plate by two bolts with a common lock washer placed under their heads. When properly aligned, the operating mechanism will be easily rotated by hand.

The fixation of the moving coil *P* is a very critical operation. The moving coil is lifted by hand and placed on the fillet of the nut *6* (Fig. 92). Each clip *8* is in turn fitted with bolt *14*, synthetic-resin-bonded paper tube *11*, washers *12* and *13*, nuts *9* and *10*, and is uniformly tightened to lock the moving coil in place. It is essential that the clip comes precisely over the pressboard band on the moving coil.

The core-coil units of phases *A* and *B* are assembled and mounted into the operating-mechanism frame in a similar way. The phases should be arranged to the drawing.

The operating mechanism is then lifted about one metre on three-grip hoisting tongs, nuts are run onto the bolts and centre-punched at three points round the circumference, and the core-coil units of all the phases are finally clamped in the frame.

After installation, the gap between the moving and fixed coils is checked for uniformity the whole length of the shaft, and the operating mechanism is tested for ease of rotation by hand.

42. Preliminary Tests of the Core-coil Assembly

The first stage in transformer assembly is followed by the tests of the core-coil unit. These tests are part of the quality control of the core-coil assembly. They are carried out by the testing station. The tests may be divided into *compulsory* and *optional*.

Compulsory tests are those which cannot be carried out after a transformer has been fully assembled. They are done in the following cases:

—the voltage taps of a core-coil assembly can only be changed by reconnecting the links on the terminal board under the tank cover (by means of a link device);

—there are parallel-connected sections in the windings (the number of turns in each coil cannot be verified in a fully assembled transformer);

—the H.V. and L.V. windings are delta-connected.

The testing of the insulation level of the top yoke bolts and of the top yoke clamps to the core is also compulsory.

Optional tests are those which can be carried out on a fully assembled transformer. Their choice depends on workmanship, the nature and percentage of rejects. At the Moscow Electrical Works the core-coil assembly is tested in all Size 3 transformers. The optional programme includes:

—the ratio test on each phase separately and at every voltage tap;

—loss and exciting-current tests.

It should be stressed that not all transformers can be tested under voltage not immersed in oil. The testing of the core-coil assembly of the Type ATMK-100/0.5 moving-coil voltage regulator is described in Section 75.

Chapter 5. Assembly of Leads and Making of Connections on the Core-coil Assembly (Stage Two)

43. General

After it has been given a preliminary test, the core-coil assembly goes to the second stage where the leads are assembled and the connections are made.

This involves two groups of operations: first, lead manufacture; second, lead assembly and the making of the connections, which also includes their insulation.

The design and connection of the leads vary with the design, arrangement and connection of the transformer windings. For Size 1 through 3 transformers the leads are made of various conductors: Grade ПБ insulated round copper wire in a variety of sizes and insulation thickness, bare rectangular copper and aluminium bars, and also round copper and aluminium wire.

H.V. leads are made of insulated Grade ПБ wire from 2.44 to 5.5 mm in diameter. This grade of wire can be easily bent to any shape. Where heavy currents are involved, use is made of bare round wire with synthetic-resin-bonded paper tubes slipped over them. L.V. leads are made of bare rectangular bars and also of bare round conductors.

In order to speed up transformer assembly, leads are manufactured either in advance or concurrently with the assembly of the core-coil unit. All lead connections are soldered only on the core-coil unit.

On the core-coil unit the leads are mounted on a frame consisting of horizontal and vertical beachwood cleats differing in length and properly braced together. The cleats are fastened with steel bolts to the top and bottom yoke clamps and also to each other.

44. Soft Soldering of Lead Connections

The soft soldering of lead connections (i.e., with a tin-base solder) produces joints which suffer from a number of drawbacks: low mechanical strength, low thermal stability, high resistance, the necessity of using flux, high cost and labour requirements (in comparison with electric brazing or electric welding).

Soft soldering is used on leads made from fine copper wire, when the joint is located close to a winding and electric welding cannot possibly be used, and also on leads made from stranded cables. The ends to be joined should be scraped bright with a knife or rubbed clean with emery paper, overlapped for a distance of 10 to 15 mm (depending on the cross section of the conductors) and banded together either with a sleeve of tinned copper ribbon 0.3 mm thick or with several bights of copper strip slitted from a similar copper ribbon.

Soldering is done with an electrical soldering iron, Grade ПОС-40 tin-base solder and soldering paste (see Chapter 3) which degreases the metal and ensures good adhesion of the molten solder to the copper. The hot tool is placed in close contact with the joint. After the joint has become sufficiently hot to melt solder, the soldering iron is withdrawn, and a stick of solder, is held against and melted into the cooling joint until it is fully filled. The winding and insulation should be protected from drops and splashes of solder with a shield of asbestos sheet or pressboard.

The stranded cable such as used in drum-type tapping switches is also soldered with Grade ПОС-40 solder and soldering paste.

45. Electric Arc Welding

Windings wound with round magnet wire up to 2.44 mm in diameter are connected to leads by electric arc welding using carbon electrodes (so-called carbon-arc welding). Copper conductors are easy to arc-weld, require no flux, and make reliable joints.

The source of welding current may be a Type ПОБС-2 single-phase 300-VA air-cooled transformer with the voltage on the L.V. side variable within broad limits. Ordinary electrodes 6 mm in diameter are used.

If a reliable welded joint is to be obtained, it is essential to remove all varnish and insulation from the ends of the conductors. Conductors of the same diameter are twisted together. If the winding wire and the lead differ in diameter, the smaller conductor is wrapped around the larger conductor to make six or seven turns as shown in Fig. 93 (*a*). The end turns of the splice are squeezed down with pliers.

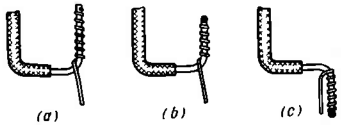


Fig. 93. Joining of round conductors by electric welding:
a—splice ready for welding; *b*—splice after welding; *c*—splice ready for insulation

One end of the transformer secondary is connected to a copper hook which is in turn connected to the lead near the splice. The other end of the transformer secondary is connected to the electrode-holder. The electrode is touched to the end of the splice and is withdrawn a short distance to initiate an arc. The arc striking between the electrode and the splice should be kept just long enough to melt the metal into a regular bead, Fig. 93 (*b*). If the arc is maintained for too long a time or too much copper is melted, the twist may be burned, leaving the ends of the conductors unwelded.

After welding, the sharp projections should be smoothed off with a file. The welded splice should be bent along the winding conductor, as shown in Fig. 93 (*c*).

As a protection from the injurious effect of the arc on his eyes, the welding operator should wear goggles with dark-blue lenses.

46. *Electric (Resistance) Brazing*

The most efficient method of joining leads is by electric (resistance) brazing. The leads are assembled into a lap-joint and brazed with phosphor-copper spelter. As com-

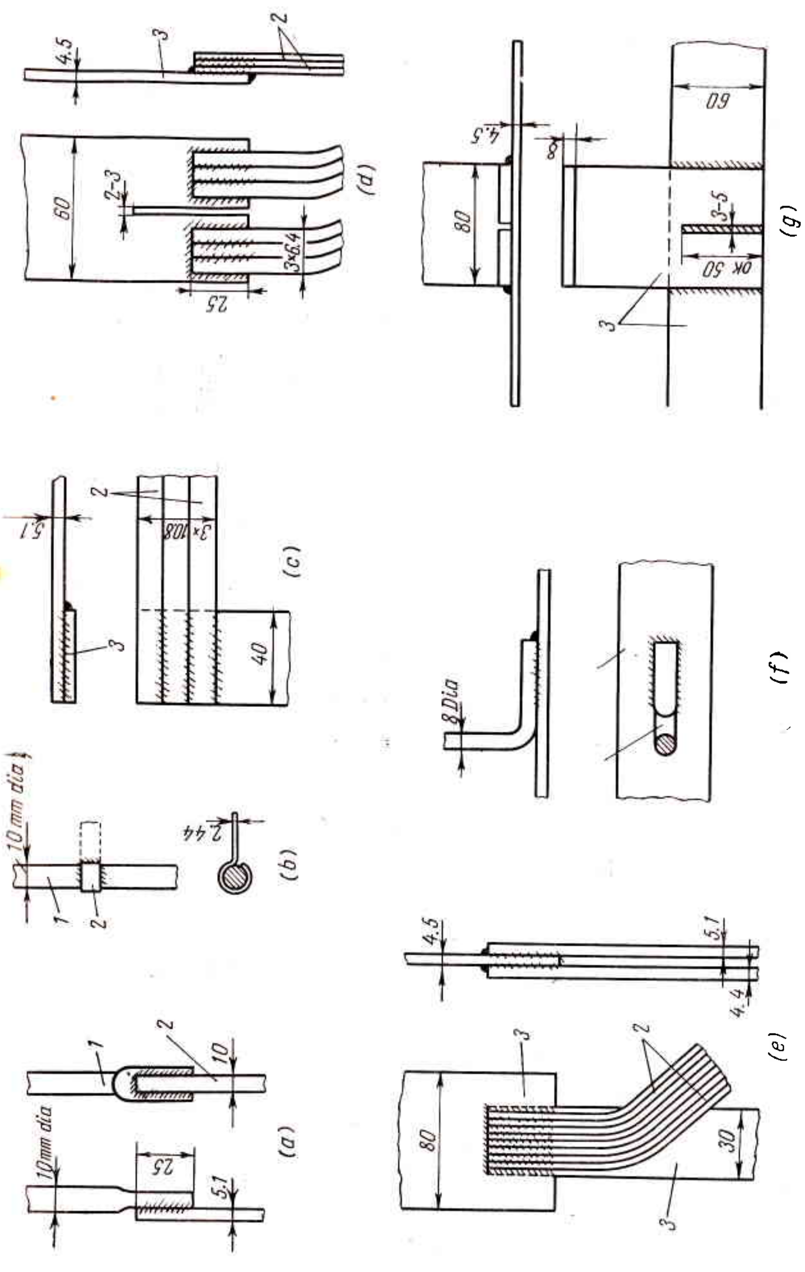


Fig. 94. Examples of electric-brazed joints:
a and *b*—winding ends joined to round-conductor leads; *c*, *d* and *e*—winding ends joined to copper bar leads; *f* and *g*—joining of leads; *1*—round-conductor lead; *2*—winding wire; *3*—bar lead

pared with soft soldering, the advantages of electric brazing are: stronger joints, better thermal stability, reduced resistance, lower cost and labour requirements, no need for banding, solder-retainer or flux. The joints most commonly used in electric (resistance) brazing are shown in Fig. 94.

Electric (resistance) brazing can be done on a stationary or a portable machine operating on 220 volts a.c. The schematic circuit diagram of a brazing machine is shown in Fig. 95.

In a portable brazing machine, the primary *1* of the brazing transformer which steps down the supply voltage from 220 to 4.23-12.7 volts is energized via a knife-switch *6* and contactor *2*. The contactor is closed by an operating coil energized from a Type AOC-0.25, 220/36-V step-down transformer *3*. The supply circuit of the contactor coil is completed by a foot-pedal switch *4*. For safety reasons, the foot-pedal switch operates from a separate 36-V circuit.

The leads to be joined are clamped in tongs *5* and are raised to the requisite temperature. Fuses *7* protect the transformer from overloads.

The brazing transformer may be a protected air-cooled portable single-phase transformer, such as Type OC-3.3/3, OCУ-20/6 or OC3-20/0.5. The transformer is mounted on rollers and is fitted with a handle for ease of manoeuvring in the assembly bay. The instantaneous current on the L.V. side is up to 1,000 amperes in the Type OC-3.3/3, up to 3,100 amperes in the Type OCУ-20/6, and up to 4,070 amperes in the Type OC3-20/0.5. The basic performance data for these transformers are summarized in Table 8. The tongs are of the portable type connected by a cable to the L.V. terminals of a soldering transformer.

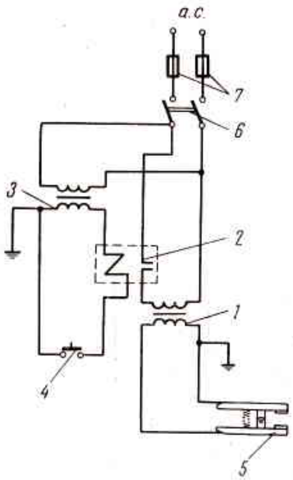


Fig. 95. Diagram showing connection of an electric-brazing machine:

1—single-phase brazing transformer; *2*—contactor; *3*—step-down transformer; *4*—foot-pedal switch; *5*—tongs; *6*—knife-switch; *7*—fuses

Table 8

Basic Performance Data for Brazing Transformers

Type	kVA rating	H.V. side				L.V. side			
		Terminals	Volts	Amperes	To link	Terminals	Volts	Amperes	To link
OC-3.3/3	2.5 (5)	A_1X	220	11.3 (22.6)	—	ax	5	500 (1,000)	—
	3.3 (6.6)	A_2X	220	15 (30)	—	ax	6.67	500 (1,000)	—
	5. (10)	A_3X	220	22.7 (45.4)	—	ax	10	500 (1,000)	—
OCУ-20/6	10 (20)	AX	220	45.5 (91)	$A_1—X_1$	ax	12.7	790 (1,580)	$a_1—x_1$
	10 (20)	AX	220	45.5 (91)	$A_1—X_1$	ax	6.35	1,580 (3,160)	$a—x_1$ $a_1—x$
	6.7(13.4)	AX	220	30.3 (60.6)	$A_2—X_2$	ax	8.46	790 (1,580)	$a_1—x_1$
	6.7(13.4)	AX	220	30.3 (60.6)	$A_2—X_2$	ax	4.23	1,580 (3,160)	$a—x_1$ $a_1—x$
OC3-20/0.5	23	AX	220	104.5	—	a_1x_2	11.3	2,035	$a_2—x_1$
	23	AX	220	104.5	—	a_1 or a_2 x_1 or x_2	5.65	4,070	$a_1—a_2$ $x_1—x_2$

Note: The kVA and amperes given in brackets apply to short-time duty.

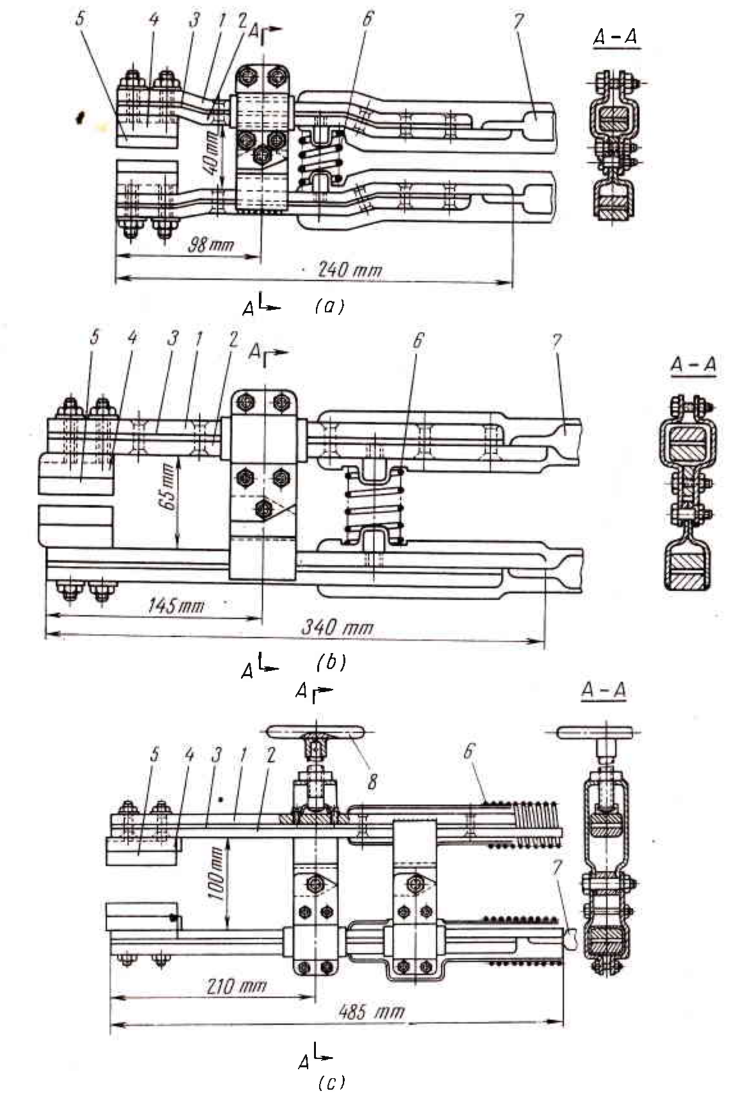


Fig. 96. Electric-brazing tongs:

a—small size; *b*—medium size; *c*—large size; *1*—steel strip; *2*—copper strip; *3*—asbestos spacer; *4*—electrode-holder; *5*—pressed-carbon electrode, Grade ЭГ; *6*—spring; *7*—cable; *8*—screw clamp

Three sizes of tongs are used to braze leads: small, medium and large (Fig. 96). The size to use depends on the size of the conductors to be joined and on the brazing current. Small-size tongs are employed to braze round copper wire up to 7 mm in diameter. Medium-size tongs are used for round conductors from 8 mm in diameter and more and also for copper bars 5 mm by 25 mm. Large-size tongs, fitted with a screw clamp *8*, serve to join copper bars over 5 mm by 30 mm in size.

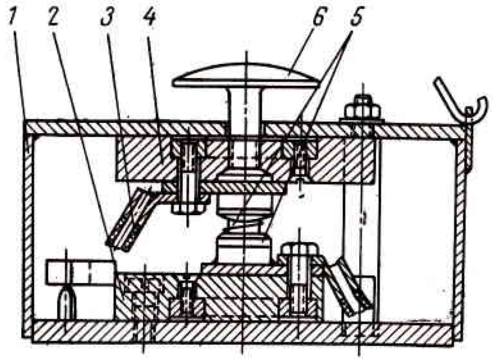


Fig. 97. Foot-pedal switch:

1—case; *2* and *4*—laminated fabric washers; *3*—cable; *5*—contacts; *6*—foot pedal

Whatever their size, tongs are of about the same design. For mechanical strength two narrow copper strips *2* are rivetted to steel strips *1*. Thermal insulation is provided by the asbestos pad *3* sandwiched between them.

To one end of the rivetted strips are attached detachable electrode-holders *4*. The electrodes may be Grade ЭГ pressed carbon (use may also be made of the stubs of arc-furnace electrodes). The other ends of the copper strips are soldered to bare copper cables 150, 240, 300 or 400 sq mm in section. The other ends of the cables are soldered to contact lugs with which they are connected to the L.V. terminals of the brazing transformer.

The cross section of the cables is determined by the size of the tongs or, which is the same, the brazing current. On the outside the cables are covered with three or four layers of asbestos tape which should be renewed at regular intervals. When the brazing transformer is energized, a current flows between the surfaces of the electrodes, and they are raised to a red heat, or over 1,300°C.

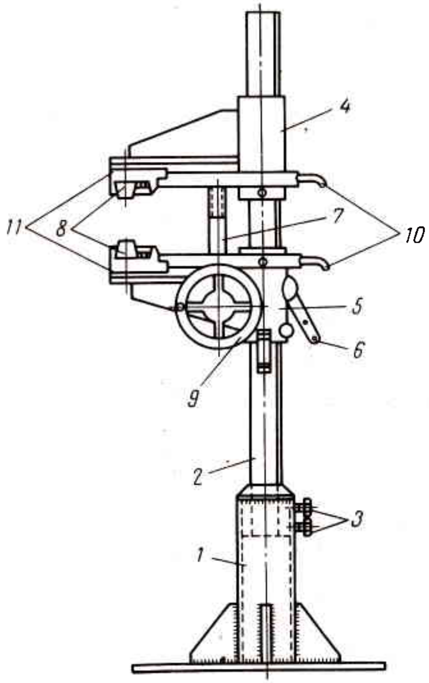


Fig. 98. Stationary brazing press:

1—upright; *2*—tubular worm-threaded rack; *3*—bolts; *4*—top platen; *5*—bottom platen; *6*—handle; *7*—screw; *8*—carbon electrodes; *9*—handwheel; *10*—cables to transformer; *11*—electrode-holders

The transformer is switched in and out by the foot-pedal switch of Fig. 97 which may be placed anywhere around the tongs, convenient for the operator.

A stationary brazing machine consists of a press and a step-down transformer. The connections in the stationary machine are shown in the diagram of Fig. 95.

The brazing press (Fig. 98) consists of an upright *1* in which is secured a steel tubular worm-threaded rack *2*. The rack is locked in the upright by bolts *3*. The top (*4*) and bottom (*5*) platens are free to move up and down the rack. The bottom platen is moved by rotating the handle *6*. Usually, the bottom platen is fixed in a definite position. The top platen can be moved by a handwheel *9* and a screw *7*.

The workpieces to be jointed are mounted on the carbon electrode *8* of the bottom platen. Rotation of the handle *6* moves the top platen down until the workpieces are tightly clamped between the top and bottom electrodes of the tongs.

Table 9

Basic Performance Data of Type OCУ-80/0.5 Brazing Transformer

kVA rating	H.V. side				L.V. side			
	Terminals	Volts	Amperes	To link	Terminals	Volts	Amperes	To link
80	*AX*	220	364	$A-X_2$ A_2-X	a_1x_5	44	1,820	x_1-a_2 x_2-a_3 x_3-a_4 x_4-a_8 x_8-a_7 x_7-a_6 x_6-a_5
53.5	*AX*	220	243	A_1-X_1	a_1x_5	29.33	1,820	
40	*AX*	220	182	A_2-X_2	a_1x_5	22	1,820	
80	*AX*	220	364	$A-X_2$ A_2-X	a_1x_4	22	3,640	x_1-a_2 x_2-a_3 x_3-a_4 x_7-a_8 x_6-a_7 x_5-a_6 a_1-a_5 x_4-a_8
53.5	*AX*	220	243	A_1-X_1	a_1x_4	14.66	3,640	
40	*AX*	220	182	A_2-X_2	a_1x_4	11	3,640	
80	*AX*	220	364	$A-X_2$ A_2-X	a_1x_2	11	7,280	x_1-a_2 x_3-a_4 x_5-a_6 x_7-a_8 a_1-a_3 a_5-a_7 x_2-x_4 x_6-x_8
53.5	*AX*	220	243	A_1-X_1	a_1x_2	7.33	7,280	
40	*AX*	220	182	A_2-X_2	a_1x_2	5.5	7,280	
80	*AX*	220	364	$A-X_2$ A_2-X	a_1x_1	5.5	14,560	a_1-a_2 a_3-a_4 a_5-a_6 a_7-a_8 x_1-x_2 x_3-x_4 x_5-x_6 x_7-x_8
53.5	*AX*	220	243	A_1-X_1	a_1x_1	3.67	14,560	
40	*AX*	220	182	A_2-X_2	a_1x_1	2.75	14,560	

The carbon electrodes are clamped in detachable electrode-holders *11* to which are connected the cables *10* from the brazing transformer. The cables should be of heavy section to avoid heating. Two cables of 400 sq mm section are used for the purpose. Each cable separately and then both cables together are given a serving of thermal insulation (asbestos tape) which should be renewed at regular intervals.

This brazing press is simple and convenient in operation. It can be easily disconnected and moved to another place. The electrodes can be readily and rapidly replaced. The operator need not use his hands to hold the workpieces. The transformer is operated by a portable foot-pedal switch.

A more recent addition to brazing plant are air-operated brazing machines. In them the top electrode-holder is lowered and the workpieces are reliably clamped by the force of compressed air.

The source of brazing current may be a Type ОСУ-80/0.5 single-phase transformer. It should be set up so as not to take any floor area. Usually the transformer is installed on an elevated platform 2 to 2.5 m above floor level and next to the press. The basic performance data for this transformer are given in Table 9.

Stationary brazing machines are employed in lead manufacture and also for brazing flexible connectors to flat bars or round conductors.

Where connections are made directly on the core-coil unit, use is made of portable brazing equipment (portable brazing tongs and a portable brazing transformer). When making brazed connections, the tongs have to be held in various positions. For convenience, they can be put on a rack (Fig. 99). The tongs are held in a cradle *1* which can be adjusted for height by means of screws *3* at will.

47. Crimping

Leads made of cables are fitted with sleeve-type terminals which are joined by crimping, using a Type РГП-7м portable hydraulic crimping tool (Fig. 100).

A salient feature of the crimping tool is that it can join a cable end and a terminal in any position. The oil reservoir *5* also serves as the handle of the tool. The handle *4* is used to transfer oil from the oil reservoir into the power cylinder *2*. The holder *1* receives both a die and the joint to be crimped.

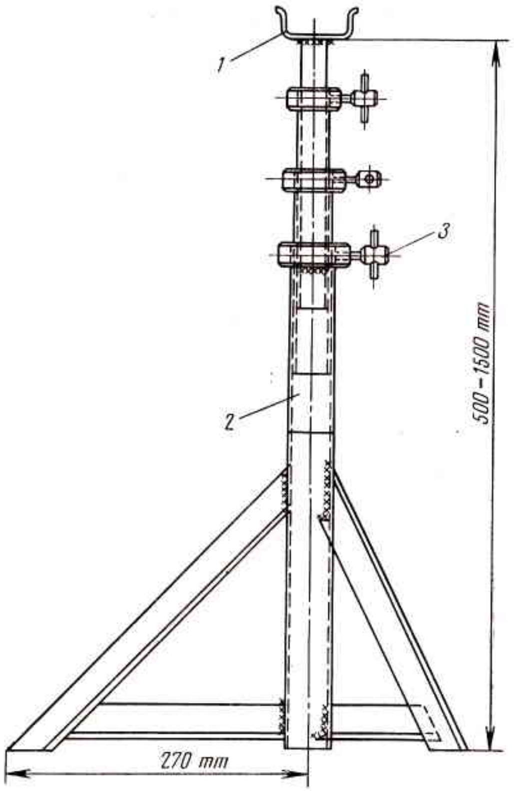


Fig. 99. Rack for brazing tongs:
1—cradle; *2*—upright; *3*—clamp screw

The portable hydraulic crimping tool operates as follows. A punch is inserted into the opening of the piston, and a mating die is inserted into the holder *1*. The pair is matched from the manufacturer's tables. The terminal slipped over the cable end is placed into the die, and the cock *7* is turned fully clockwise. The tool slung on a strap from the operator's neck is held in the left hand (by the oil reservoir *5*), and the oil pump (the handle *4*) is operated by the right hand. The pressure in the pump is built up until the punch and the die close. Then the cock *7* is given two or three turns counter-clockwise to release the pressure, and the crimped joint is removed from the die.

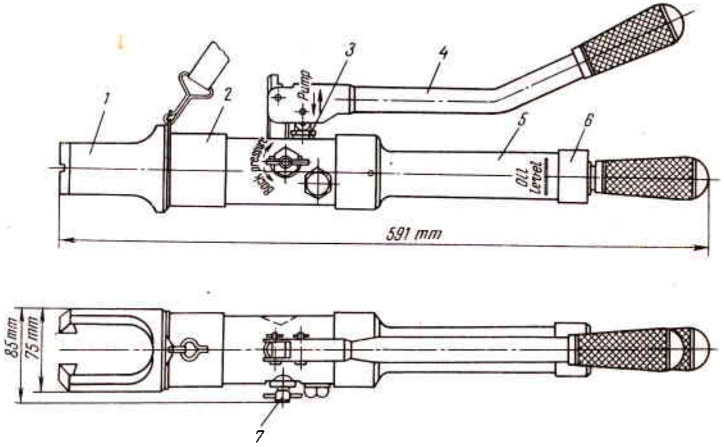


Fig. 100. Type. РГП-7m portable hydraulic crimping tool:

1—holder; *2*—power cylinder and main piston; *3*—plunger pump built into power cylinder; *4*—pump handle; *5*—oil reservoir; *6*—cap nut; *7*—screw cock

The tool has a relief valve adjusted for a maximum pressure of 55 atmospheres.

The working fluid may be thoroughly filtered motor oil, machine oil, or transformer oil. With the tool in the upright position and with the piston fully withdrawn, the oil level in the reservoir should be within 25 mm of the top edge of the reservoir. The cap nut *6* should be tightened to make the joint oil-tight.

The Type РГП-7m tool can be used on cables from 16 to 240 sq mm in section. It has assorted dies and other accessories.

48. Cold Pressure Welding (Bonding)

For some time past there has been an ever increasing use of round aluminium wire for transformer windings and of aluminium bar for leads. However, the complete replacement of copper by aluminium in the manufacture of leads is not always possible. Aluminium leads connected to binding posts by means of clamps or screws become quickly oxidized, the contact burns and fails, so that the transformer may be damaged beyond repair.

For reliability, bolted connections should never be used to join aluminium to aluminium or copper to aluminium. Instead, even on aluminium leads, contact should be only made between copper terminations. This purpose is served by *cold welding* (*bonding*) of copper connectors to the ends of aluminium coil wire or terminal leads.

Cold pressure welding, or bonding, is a process for metal joining, in which use is made of deep plastic deformation at the joint without heating. The process can join copper to copper, aluminium to aliminium, and copper to aluminium. Bonded joints are strong mechanically and have low electrical resistance. For a sound bond to be obtained, it is all-important to prepare the ends to be joined properly. The ends of conductors up to 3.05 mm in diameter should be squared with cutting pliers (Fig. 101). The pliers must be thoroughly degreased with petrol or acetone before use. Connectors for joining aluminium wire up to 10 sq mm in section to copper wire up to 6 sq mm in section can be made on the Type CHC-3 bench tool (Fig. 102).

In coil winding, connectors are bonded to the first and last turns by means of the Type KC-6 tongs (Fig. 103). The tongs have a movable clamp *2* and a stationary clamp *3*. The movable clamp is free to move on the spindles *1* built into the body *5*. The wires to be joined are secured in the clamps so that they stick out of the dies *4* for a definite distance. The upset force (the bonding pressure) is applied to the wires through the movable clamp by the upsetting cam *7* which rotates as the fixed handle *6* and the movable handle *8* are squeezed together.

Heavier wire is squared either in a special fixture or with shears (Fig. 104), so as not to flatten the ends. The

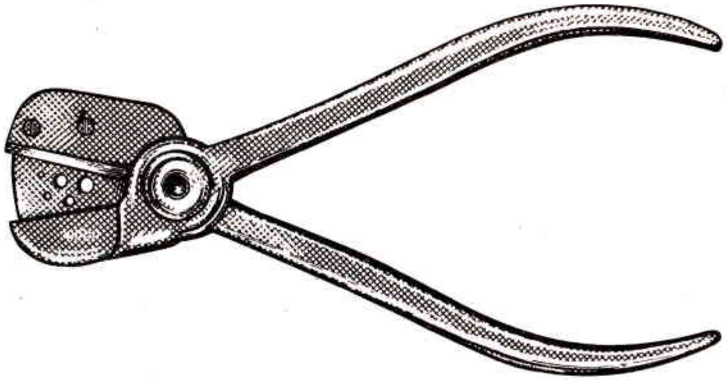


Fig. 101. Cutting pliers to square ends of wires prior to cold welding (bonding)

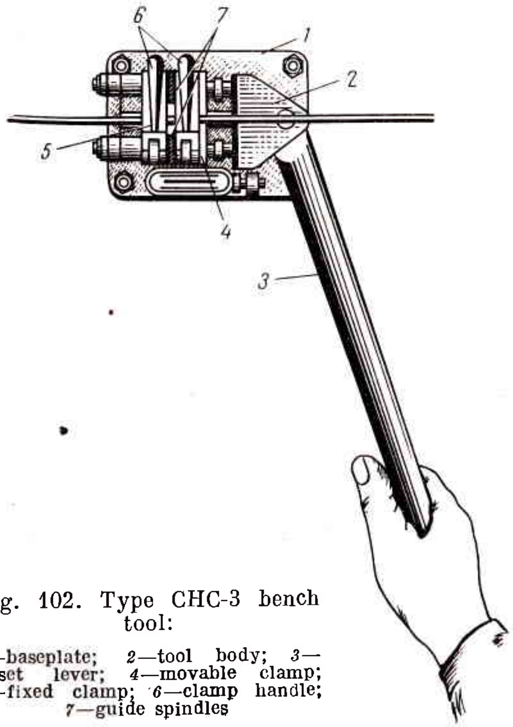


Fig. 102. Type СНС-3 bench tool:

1—baseplate; 2—tool body; 3—upset lever; 4—movable clamp; 5—fixed clamp; 6—clamp handle; 7—guide spindles

end of the copper conductor should be annealed and that of the aluminium conductor degreased with petrol or acetone, and both should be roughed with a bastard file on the

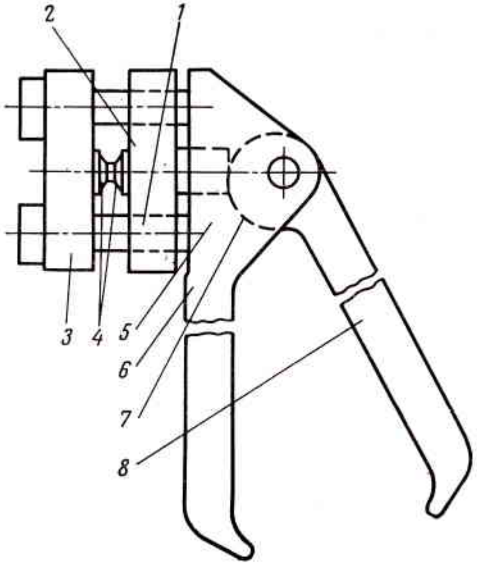


Fig. 103. Type КС-6 tongs:

1—guide spindle; 2—movable clamp; 3—stationary clamp; 4—dies; 5—tongs body; 6—fixed handle; 7—upsetting cam; 8—movable handle

faces before bonding. One side of the file should be used only for copper and the other only for aluminium. The file should be protected from grease and dirt. It is likewise important to keep dirt, moisture and grease away from the cleaned faces of the conductors to be butt-joined. For the same reason, they should never be touched with fingers.

Copper and aluminium conductors with a cross section of up to 220 sq mm are butt-bonded on the Type МСХС-35 machine (Fig. 105). The copper conductor is secured in the fixed clamp, and the aluminium conductor in the movable clamp with the same stick-out (the distance for which they project from the clamps). The distance between the clamps is adjusted by means of change washers *6*. The maximum distance should not exceed two diameters of the conductor being joined.

Upset pressure is applied to the faces of the conductors by means of the lever *7* of the hydraulic upsetting mechanism until the clamps touch each other (the pressure gauge *3* will read the upsetting force). Then the axial pressure is relieved, the copper piece unclamped, the clamps drawn apart by means of the hydraulic-valve levers *11* and *12*, and the aluminium piece unclamped.

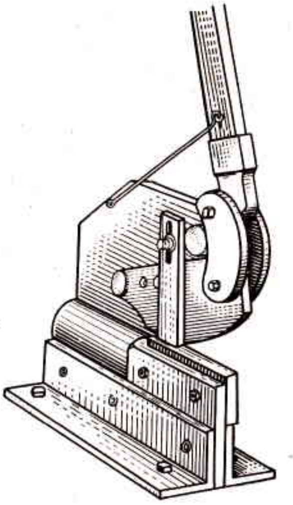


Fig. 104. Hand-operated lever shears

Then the bonded joint is again secured mid-way between the clamps, the same levers are operated to apply pressure, and the joint is finally upset until the clamps touch each other. After that, the pressure is relieved, the clamps drawn apart, and the bonded workpiece removed from the machine. The squeezed-out metal is removed on a suitable fixture.

The quality of bonded joints is tested at random by a 90-degree bend test, with the specimens clamped in a vise.

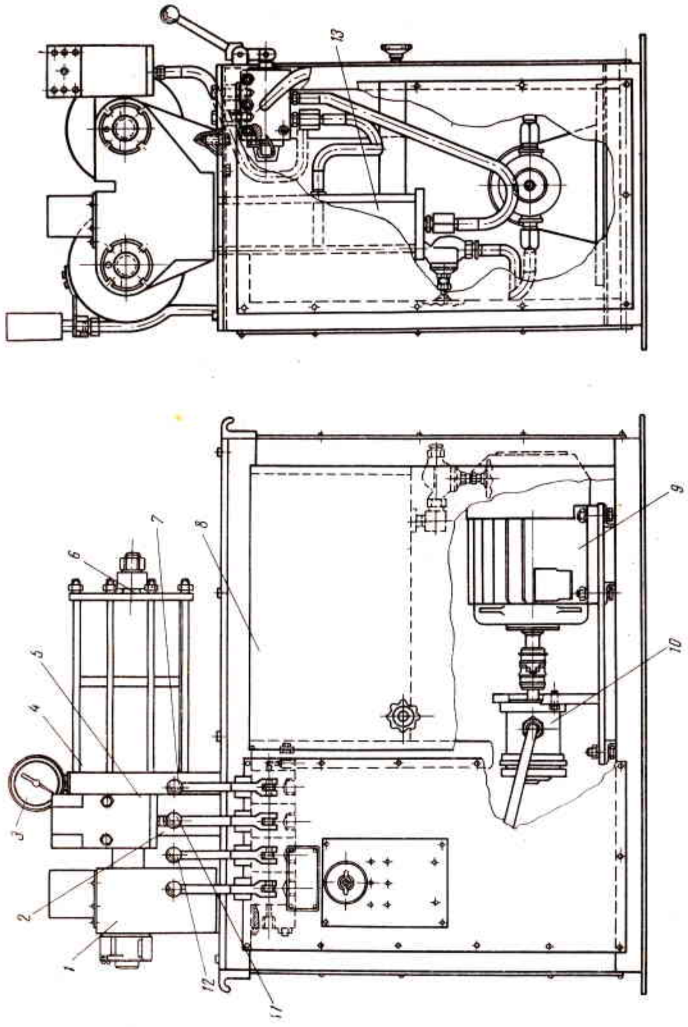


Fig. 105. Type MCXC-35 cold-pressure welding machine:

1—movable platen; *2*—stationary platen; *3*—pressure gauge; *4*—upsetting-mechanism cylinders; *5*—squaring cutter for joint preparation; *6*—change washers; *7*—hydraulic-valve levers; *8*—oil tank; *9*—electric motor; *10*—hydraulic pump; *11*—right-hand-clamp hydraulic-valve lever; *12*—left-hand-clamp hydraulic-valve lever; *13*—clamping-mechanism cylinders

49. Argon-shielded Welding

Transformer makers are widely using argon-shielded welding for joining aluminium. The process produces joints of very high quality and at a very high rate.

In the Soviet Union, aluminium is argon-shielded arc welded on Type ПШП-10 portable units operating at 20-25 volts, 150 amperes and using a consumable electrode—Grade A1 aluminium wire 1 to 1.5 mm in diameter. The welding outfit includes: a torch or welding gun complete with power cables, a control cabinet, a Type ПСО-300 or ГСР-9000 motor-generator set, a ballast rheostat, an argon cylinder complete with a pressure regulator and a hose, and a wire-feed device consisting of a wire reel, a motor, a flexible metal tube and a director nozzle. The welding outfit is set up and connected as shown in Fig. 106.

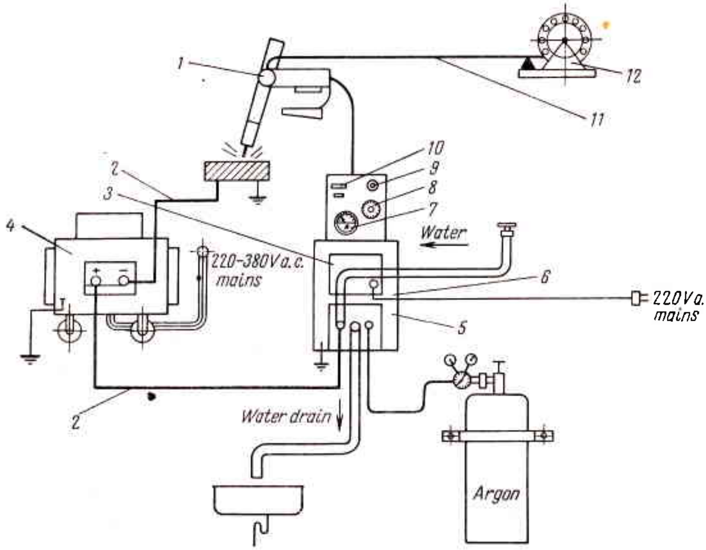


Fig. 106. Connection diagram of Type ПШП-10 semi-automatic argon-shielded arc welding outfit:

1—welding torch or gun; *2*—welding cable, 50 mm dia; *3*—switch; *4*—source of welding current; *5*—control cabinet; *6*—control panel; *7*—ammeter; *8*—wire-feed rheostat; *9*—pilot lamp; *10*—wire-feed reversal switch; *11*—wire-feed tube; *12*—wire reel

Before it is wound on the reel *12*, aluminium wire is degreased with aviation spirit or acetone. Prior to the welding operation, the toggle switch on the control panel *6* of the control cabinet *5* is flipped into the "Reverse" position and the packet switch *3* is closed. The pilot lamp *9* goes on to indicate that the supply circuit to the control cabinet has been completed. The welding speed is set on the control panel: the rheostat is set to 35-40 for round conductors of small cross section and to 25-30 for aluminium bar.

Now the aluminium wire sticking out of the director nozzle is touched to the workpiece. Pressure on the switch on the handle of the torch *1* energizes the solenoid valve which opens for the emission of argon into the nozzle. Another pressure on the switch energizes the contactor which completes the welding circuit and the relay which starts the wire-feed motor. As the wire withdraws, an arc strikes between the workpiece and the wire, and a current begins to flow in the welding circuit. The relay now operates to reverse the motor, and the wire is fed into the joint. The progress of welding is watched through a face shield having a window fitted with a suitable filter or welding lens.

The stick-out of the wire from the director nozzle is maintained between 12 and 20 mm. The torch is held so that it is at 70° to 80° to the weld (Fig. 107) and travels in a leftward direction. At the end of the weld, the crater should be brought out onto the parent metal and filled up completely. To stop the welding operation, the switch on the torch is released and the welding circuit is interrupted.

The quality of welded joints is to a great extent dependent on edge preparation and joint fit-up. The leads to be welded should be degreased with aviation spirit or acetone and lap-assembled on a suitable jig or fixture (depending on their shape). Aluminium leads of small cross section are assembled on the fixture of Fig. 108, while aluminium wire is welded to aluminium bar in the fixture of Fig. 109.

Instead of a fixture, small-section aluminium leads may be welded on a steel backing plate to keep the molten bath from running out and the workpieces from sagging. During the welding operation, the coils and insulation of the core-coil unit should be protected from splashes of molten metal with a shield.

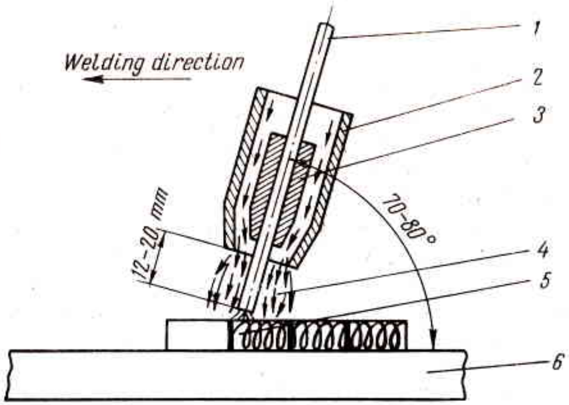


Fig. 107. Diagram showing the argon-shielded arc welding process: *1*—electrode wire; *2*—torch or gun; *3*—electric conductor; *4*—argon jet; *5*—winding wire end; *6*—aluminium bar

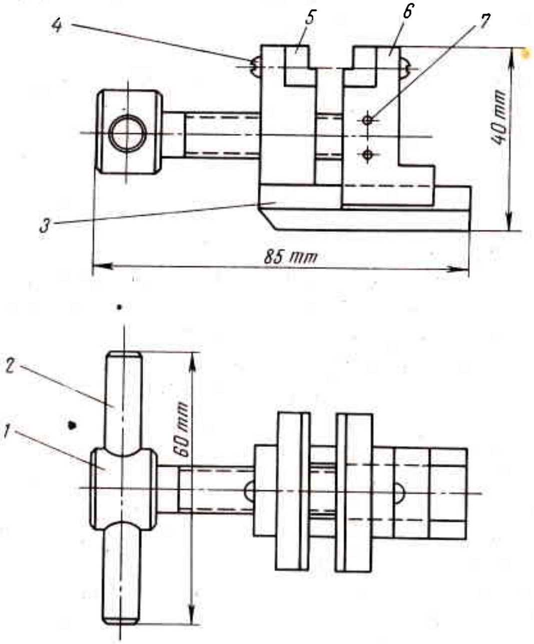


Fig. 108. Fixture for welding aluminium leads of small cross section: *1*—pressure screw; *2*—handle; *3*—body; *4*—screw; *5*—change jaw; *6*—slide; *7*—pin

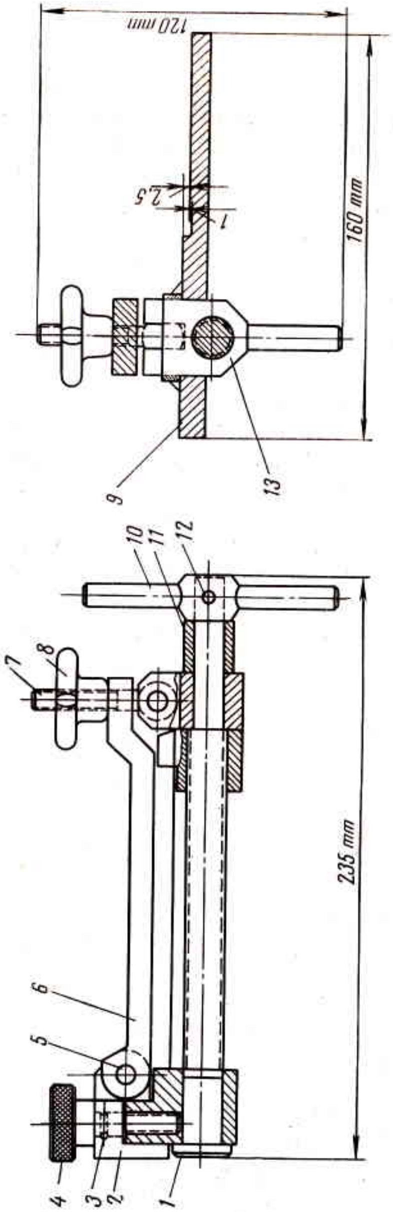


Fig. 109. Fixture for welding aluminium wires to aluminium bars: *1*—screw; *2*—retainer; *3*, *5* and *12*—pins; *4*—clamp screw; *6*—strip; *7*—swing screw; *8*—shaped nut; *9*—body; *10*—handle; *11*—bushing; *13*—jaw

50. *Manufacture of L.V. Leads*

For all the multitude of lead designs, each may be divided into the lead proper (that part which is connected to a winding end) and the lead contact (that part which is connected to a terminal bushing).

Leads proper are made of round copper wire or copper bar, while lead contacts are made either as flexible connectors from copper ribbon or as lugs from copper angles or plates.

Leads and lead contacts are manufactured separately and are then joined by soldering, brazing or welding, depending on lead design.

Manufacture of Leads from Copper Bar. Copper bar can be made in a variety of lead types. Fig. 110 shows some of them. Whatever the shape and section of leads made from bare copper bars, the operations involved in their manufacture are the same, although they differ in the labour required to perform them.

The dimensions of lead blanks are specified in lead drawings. The drawings give the developed length of a lead, thereby saving trouble of determining it. Also, the drawings give the length of each leg of a lead, i.e., from bend to bend.

Copper bar is cut into lead blanks on a bar cutter driven by a 1-kW, 1,440-rpm electric motor (Fig. 111). The copper bar *1* is pressed to the top platen *5* of the machine by two clamps *4* under which a slab *6* is placed. The cutting tool *2* is fed horizontally into the bar by rotation of a handwheel, and cuts off a blank. The tolerance on blank length is +3 mm. On the cut-off blank the number it is assigned in the drawing is stamped on its flat side.

It is essential to check the blanks for camber and bowing. If necessary, the defective blank should be straightened. In the case of bowing, the blank should be laid on a bench or a cast-iron plate with the convex side up, held in place by the left hand and struck slightly with a wooden or copper mallet held in the right hand. The result should be checked by looking along the blank.

In the case of marked camber, the blank should be heated where the camber is most pronounced. The blank should

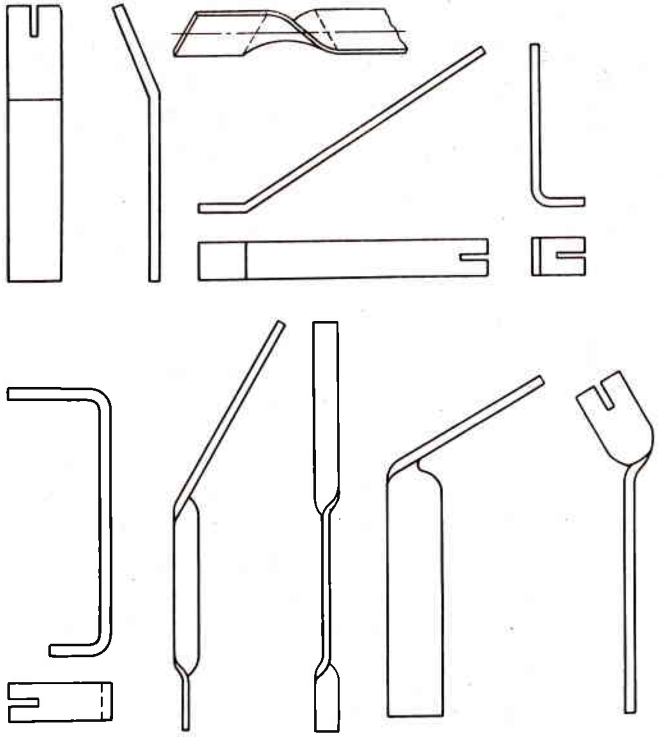


Fig. 110. Leads from copper bars

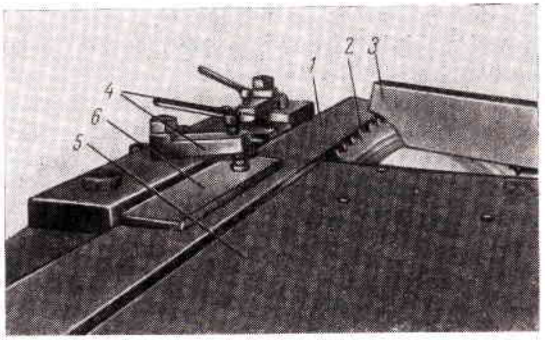


Fig. 111. Copper-bar cutter:
1—bar; *2*—cutting tool; *3*—guard screen; *4*—clamps; *5*—top platen; *6*—slab

be heated in the tongs of a brazing machine. The straightened blanks are then marked out for bending and notch-milling. The dimensions and some of the types of notches are shown in Fig. 112.

Notches are milled in leads when several groups of coil wires have to be connected to the same lead. Also, when two bars of different size are to be joined, a notch should be milled in one of them. Notches are necessary in order to separate joints (so as to reduce heat transfer and protect the previous joint from heating), and also to give access to the connections to be made.

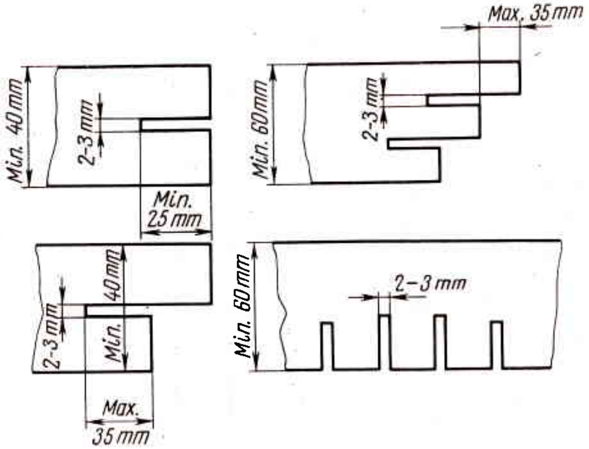


Fig. 112. Notches in bar leads

Notches are milled on a bar-cutter. The marked-out end of a blank is brought to the milling tool so that the notch can be made along the marking line. For convenience in bending, blanks are always marked out on the inner side, i.e., where the bar makes an angle less than 180° after bending.

Marked-out blanks are bent on flat on a bending machine equipped with an air-operated clamp and a mechanical drive (Fig. 113). On this machine, both bending and clamping are mechanized, and the operator can bend bars measuring up to 12.5 mm by 100 mm to a high degree of accuracy and at a high rate without much physical effort.

The machine is driven by a 1-kW, 1,440-rpm electric motor *1* via a flexible coupling *3*. The requisite angle of bending is maintained by a shoe-brake *2* actuated by an electromagnet. A gear train consisting of a pair of spur gears *4* and *5*, a worm pair *6* and gear *7* actuates the big gear *8* mounted on a steel bushing. The top end of the bushing is the body of the clamp. Inside the gear *8* is located the air-operated membrane-type clamp *9*.

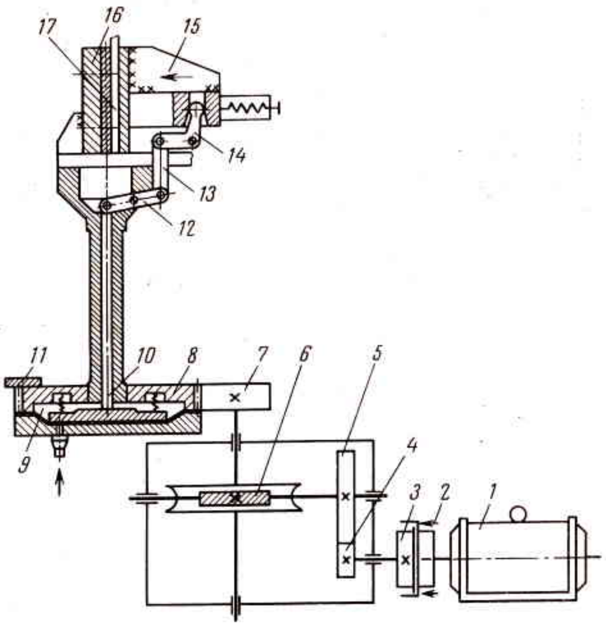


Fig. 113. Diagram of a bending machine:

1—electric motor; *2*—shoe brake; *3*—flexible coupling; *4*, *5*, *7* and *8*—gears; *6*—worm pair; *9*—clamp; *10*—spindle; *11*—limit stop; *12*—two-arm lever; *13*—link; *14*—bell crank; *15*—movable jaw; *16*—fixed jaw; *17*—bar to be bent

The clamp *9* transmits clamping force to a spindle *10* and a two-arm lever *12* which acts through a link *13* to actuate the bell crank *14* and the movable jaw *15*. When the

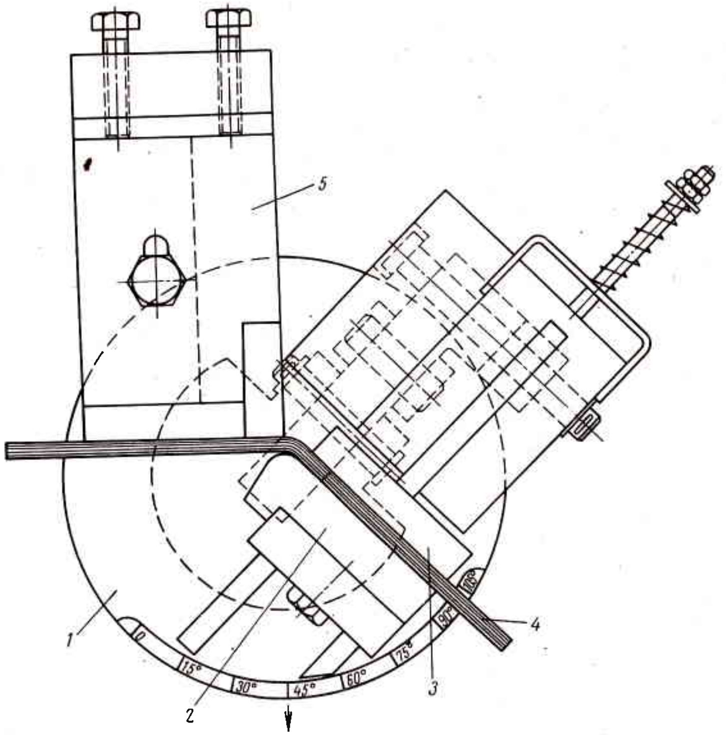


Fig. 114. Work head of the bending machine:

1—dial; 2—fixed jaw; 3—movable jaw; 4—bar to be bent; 5—adjustable limit stop

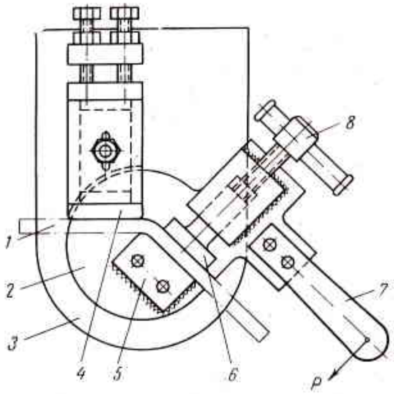


Fig. 115. Hand-operated bender:

1—bar to be bent; 2—rotary segment; 3—baseplate; 4—thrust block; 5—front jaw; 6—rear jaw; 7—lever; 8—screw

pressure in the air mains is 3 atm, the movable jaw clamps the bar *17* against the fixed jaw *16* with a force of 2,500 kg. The angle of bending can be set on the dial mounted on top of the bench or by means of the limit stops *11* which operate the limit switches.

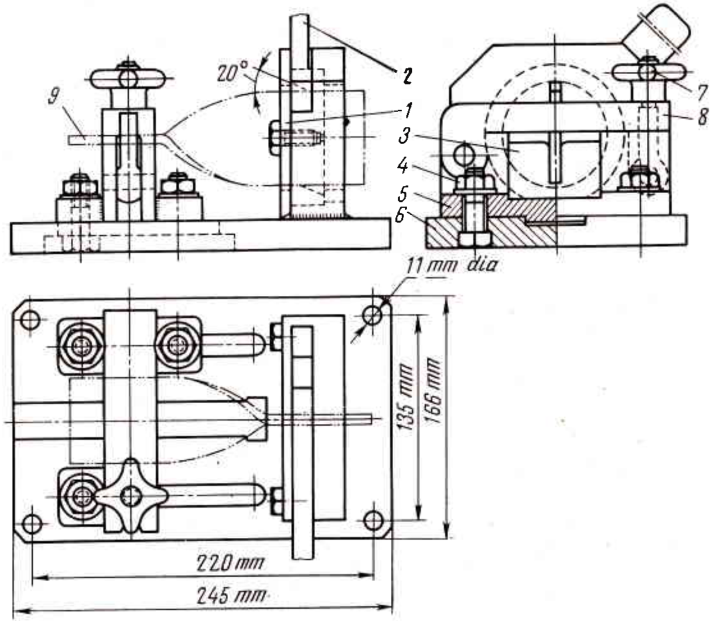


Fig. 116. Tool for twisting copper bars:

1—flange; 2—swinging tommy-bar; 3—change dies; 4—steel bolt; 5—movable clamp; 6—tool body; 7—nut; 8—steel cover-strap; 9—copper bar to be twisted

Fig. 114 gives a top view of the bending head with a bent bar. The machine has an overload feature. In the case of an overload, the hardened bushing in the gear hub shears off the overload pin.

Bars can also be bent with a hand-operated bender (Fig. 115). The bar *1* to be bent is placed precisely along the marking line in the gap between the front jaw *5* and the rear jaw *6*. The gap width, which varies with bar thickness, is set by means of a screw *8* which positions the rear jaw as required. The position of the thrust block *4* also changes accordingly. Then the segment *2* is turned by the lever *7*, and the bar is bent to the requisite angle.

Some of the L.V. leads on a transformer have to be given a quarter-turn twist (see Fig. 110). Twisted leads from standard copper bar measuring 4.4×25 mm, 4.4×30 mm, 5×40 mm or 5×60 mm can be made with the tool of Fig. 116. The tool consists of a body *6*, a swinging tommy-bar *2*, a movable clamp *5*, and change dies *3*. The requisite length of the twist is set by moving the clamp in the groove in the body and securing it by three bolts *4*. For each size of copper bar there is a definite size of die and tommy-bar. The die is inserted into the two grooves in the clamp. The tommy-bar is held in the body by a flange *1*. The slot in the end of the tommy-bar has its sides chamfered to an angle of 20° so that the twisted bar can be easily removed.

To make a twist, the cover-strap *8* is thrown open, one end of the bar is inserted into the slot of the tommy-bar held horizontally, and the other end is laid on the cover-strap which is now turned over the bar and is locked by a nut *7*. Then the tommy-bar is pulled as far as it will go, and the bar is given a quarter-turn twist.

51. Manufacture of Leads from Round Wire

Leads made from round wire 10 to 12 mm in diameter are employed in Size 1 transformers and moving-coil voltage regulators. In some of them, the leads are fairly complex in shape. This is especially true of the Type ATMK-100/0.5 moving-coil voltage regulator (Fig. 117).

The first step in making an odd-shaped lead is to mark out bends and flats. Then the blank is cut off on lever shears or a universal shear-punch-bar cutter (Fig. 118). The cutoff blank is straightened on a bench block or a cast-iron plate.

For convenience in electric brazing and also to obtain a large area at the brazed joint, the round wire is usually flattened at the ends, i.e., where it is to be joined to the winding ends, flexible connectors or angle lugs. To do this, the copper wire is heated in a brazing press and is flattened at the ends with a hammer on a bench block to about half the wire diameter.

For bending, a round-wire blank is clamped in a vise, a steel tube is slipped over it, and the blank is bent to a template. Large-diameter wire, prior to bending, has to be heated in a stationary brazing machine, then clamped in a bench vise and bent with hammer blows. The bends are checked for angle or radius against a template. As a rule, the operation has to be repeated several times before the requisite bend is obtained.

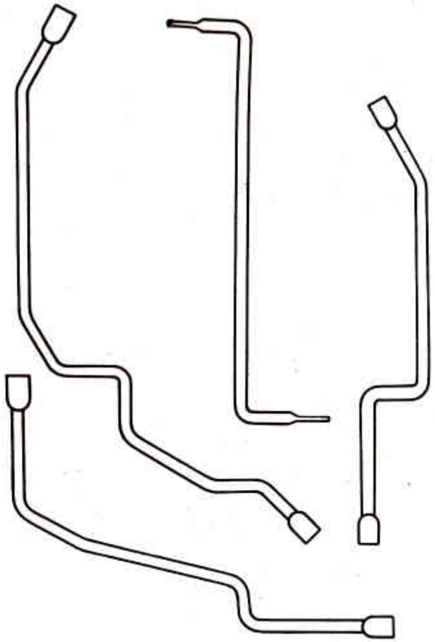


Fig. 117. Leads made from round copper conductors

In all cases, flats and bends should be made to the dimensions specified in the drawing.

52. Manufacture of Flexible Connectors

Flexible connectors are made of copper ribbon 0.3 mm thick and 30 to 80 mm wide. The number of plies in, and the width of, a flexible connector depend on the cross sec-

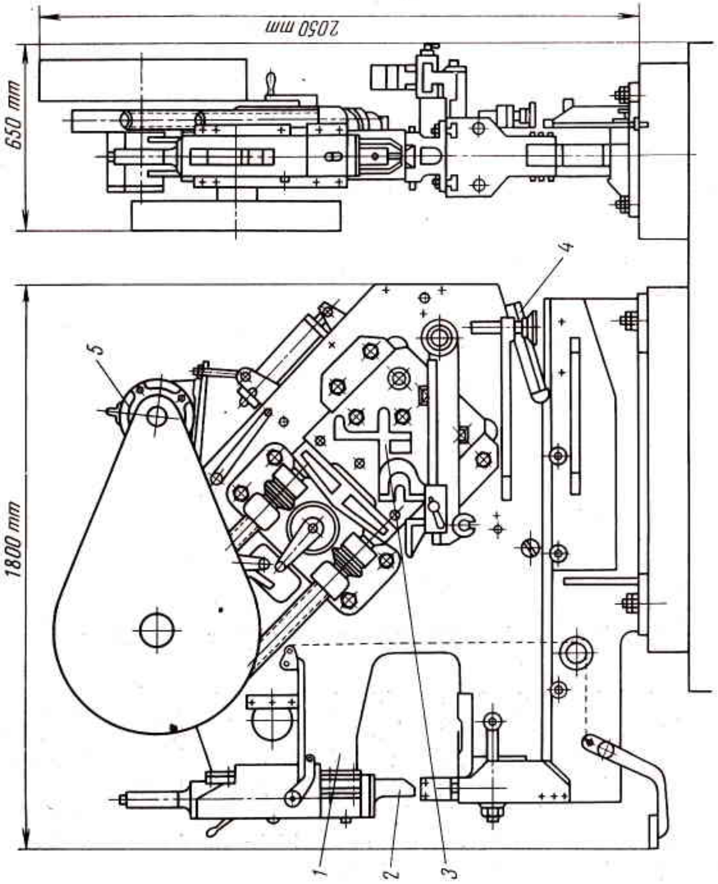


Fig. 118. Model НА-633 universal shear-punch-bar cutter:
1—bedframe; *2*—punch; *3*—shape-cutting blades; *4*—strip and sheet-cutting blades; *5*—electric motor

tion of the round wire or bar to which it is to be joined, i.e., on the current flowing in the lead.

Flexible connectors are made by winding copper ribbon on a copper mandrel 2.83 to 4.4 mm thick. The length of the mandrel should be equal to the length of the flexible connector less its thickness.

Fig. 119 shows a flexible connector wound on a mandrel. The copper ribbon should be wound as tightly as possible, and there must be a whole number of plies. The length of the ribbon from a bend to the line of cut should not be greater than the length of the joint between the flexible connector and the lead.

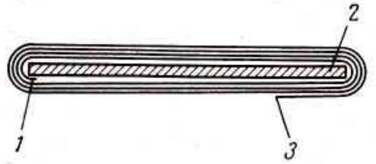


Fig. 119. Flexible connector made from copper ribbon wound on a mandrel:

1—start of ribbon; *2*—mandrel; *3*—finish of ribbon

After it has been removed from the mandrel, the flexible connector is swaged over the entire contact surface with a hammer through a copper block. Then the contact surface is sweated and tinned. On different connectors, this operation is done differently.

Flexible connectors for connecting a winding lead to a terminal bushing are relatively thin, and they are tinned and sweated simultaneously by dipping into a pot of molten tin-base solder (Grade ПОС-30). Before dipping, a connector should be immersed into a solution of hydrochloric acid and zinc chloride to half its width for one minute or two.

To avoid violent fuming, the connector should be dipped slowly. The operator should wear goggles and gauntlets as a protection against splashes of molten solder.

The contact surface of the flexible connector removed from the molten-solder bath is wiped with a broad brush, and the connector is quickly compressed in an air- or hand-operated press while hot. Then the connector is rinsed first with hot then with cold running water and blown with compressed air.

The excess solder squeezed out on the sides of the connector is removed with a file. The hole for the terminal is first marked out on a hole-marker (Fig. 120) and is then punched on a universal shear-punch-bar cutter. Then the connector is straightened on a steel block with hammer blows through a copper plate and bent to a half-circle over a template or a mandrel.

Flexible connectors for special-purpose transformers are sweated with phosphor-copper spelter solder. The contact surface is clamped between the carbon electrodes of a stationary brazing machine. For uniform heating, the electrodes must be snugly clamped to the sides of the connector.

When current is switched on, the carbon electrodes become incandescent and heat the clamped connector to a bright-red or light-yellow heat (the melting point of the solder). While maintaining this temperature by switching the current on and off, the sides of the connector are brushed with a stick of phosphor-copper solder several times. On coming in contact with the hot sides of the connector, the solder melts and fills the space between the plies of the copper ribbon. As soon as the solder has filled all spaces (and excess solder begins to appear on the sides), the current should be switched off, the copper allowed to cool to a dark-red heat, and the connector removed from the clamp.

The cooled connector is filed to remove scale and surplus solder. The holes are marked and punched, and the contact surface is straightened as in the case of flexible connectors sweated with tin-base solder.

After the hole has been punched, the flexible connector sweated with spelter solder is tinned by a galvanic process.

For some of the leads in special-purpose transformers the lead contact lugs are made from copper angles or plates in a variety of shapes (Fig. 121). Blanks for angle and plate lugs are cut from copper bar on a bar-cutter. The blanks

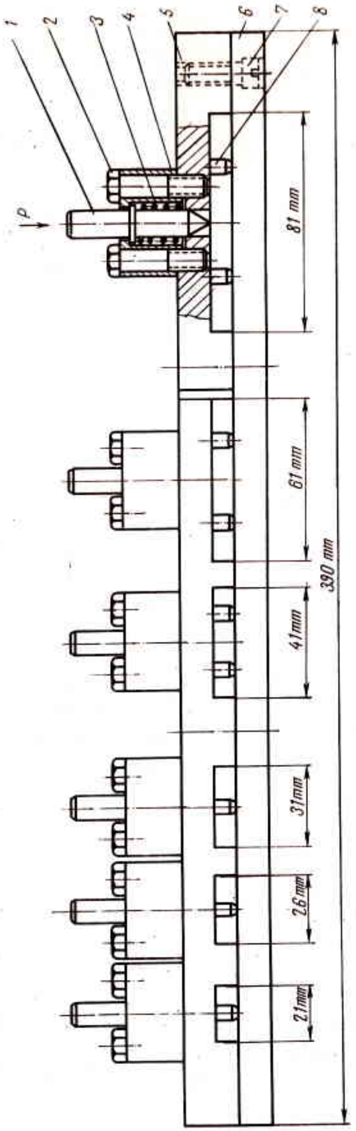


Fig. 120. Hole marker:

1—centre-punch; *2*—bolt; *3*—spring; *4*—bushing; *5*—body; *6*—baseplate; *7*—screw; *8*—dowel are marked out, trimmed and punched on a universal shear-punch-bar cutter. Angles are usually bent after the holes in them have been punched.

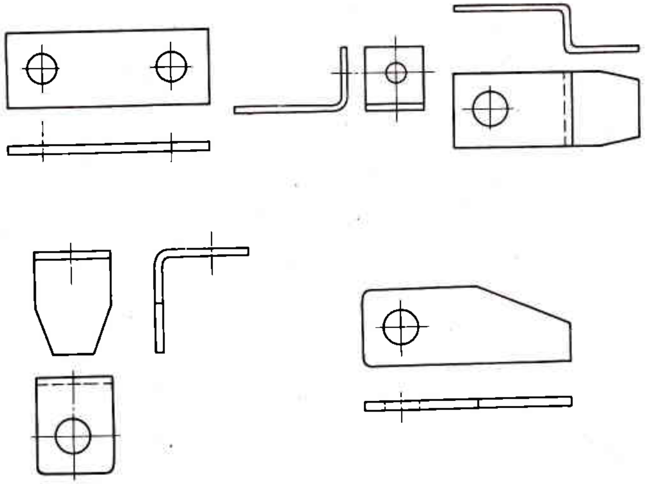


Fig. 121. Lead contacts made from copper bars

Then the blank is clamped in a bench vise, and the sharp corners and edges are rounded with a file all the way round the perimeter. The contact surfaces are tinned after connection to a lead made of copper bar or round wire.

53. Joining of Leads to Flexible Connectors

Leads and flexible connectors are joined by brazing with phosphor-copper spelter solder on an electric brazing machine. For uniform heating, the carbon electrodes of the tongs should have parallel contact surfaces. If necessary, these surfaces should be dressed and cleaned with a file.

The pieces to be brazed are clamped tightly between the electrodes, with the broader part (the lead or the flexible connector, whichever may be the case) below (Fig. 122). As a protection against injury, the parts to be brazed are packed around with wet asbestos.

Then the transformer of the brazing machine is energized by pressure on the foot-pedal switch. The electrodes and the parts are gradually heated to a red heat. Phosphor-copper solder usually begins to melt at this temperature. If a bright spot appears where the electrodes touch the parts, the transformer should be switched off, and more pressure applied to the joint, lest the copper should burn.

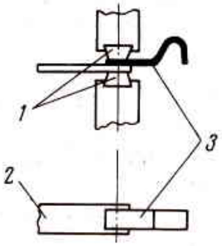


Fig. 122. Brazing a flexible connector to a bar lead:
1—carbon electrodes of brazing press; *2*—bar lead; *3*—flexible connector

The transformer should not be kept energized for a long time, because the surface of the conductors may melt before the joint is heated throughout. To avoid this, the transformer should be switched on and off intermittently by depressing and releasing the foot-pedal switch. However, the heating of the joint should not be carried on too long, for the joints already brazed may be destroyed. The parts should be heated uniformly across the entire thickness of the joint and brought to a bright-red or light-yellow heat (but not the white heat) simultaneously.

Then the joint is brushed from all sides with a stick of phosphor-copper solder so that it flows in between the parts being joined and fills all the voids between the conductors. As soon as the solder fills all of the joint (which will be indicated by surplus solder appearing on the sides), current should be turned off, the joint allowed to cool to a dark-red heat, the top electrode lifted, and the joint removed from the clamp. For rapid cooling, it is customary to dip the joint into water for 20 to 30 seconds. Then the joint is worked with a file and rubbed with emery cloth to remove scale and excess solder.

54. Assembly of H.V. Leads on Size 1, 6-kV Transformers

In Size 1 transformers in which the core-coil unit is not attached to the tank cover, the H.V. windings are usually star-connected. Voltage taps are changed by a nine-terminal tapping switch giving a voltage variation of ±5 per cent and mounted on the core-coil assembly. The switch is of the neutral-point type, because it forms the neutral point of the star connection by shorting the following terminal studs:

— X_1—Y_1—Z_1 for the + 5 per cent tap (all of the turns are brought in circuit);

— X_2—Y_2—Z_2 for the "normal" tap (the middle number of turns are in circuit);

— X_3—Y_3—Z_3 for the —5 per cent tap (the least number of turns are in circuit).

Lead Manufacture. The first step in the assembly of leads is to make them from Grade ПБ cable-paper-covered round wire. The length and diameter of the wire are ordinarily given in the lead drawing. The cable-paper insulation is wrapped with twisted brown thread some 8 to 10 mm back of the end to be skinned. The thread is applied as follows: it is doubled on itself so as to make a loop, the loop is laid along the wire, five or six turns of thread are wrapped around the loop and wire, the finish of the thread is passed into the loop, and the loop is tightened by pulling at the start, as shown in Fig. 123.

Then the leads are skinned on a stripper (Fig. 124). The tapping leads are skinned for a distance of 150 mm, and the line leads for a distance of 180 mm from the end. The stripper operates as follows. The wire *1* is clamped between the jaws *2* by means of an eccentric *3*. The end to be skinned is placed between blades *8* and *9*. The top blade *9* is moved by a foot pedal *6* and a link *7* towards the bottom blade. The blades cut through the insulation, and the wire clamped in the jaws *2* is pulled to the right by a pinion *5* and a rack *4*. The insulation to the left of the blades is pulled off the wire (Fig. 125). The blades should be matched to the diameter of the wire to be skinned, so that the conductor will not be nicked.

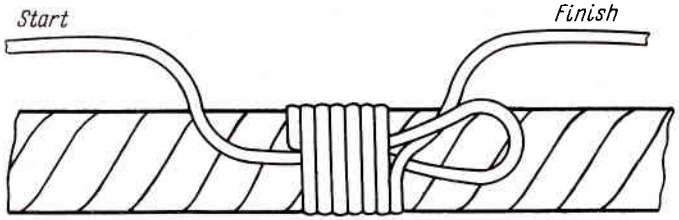


Fig. 123. Securing the insulation on a copper wire

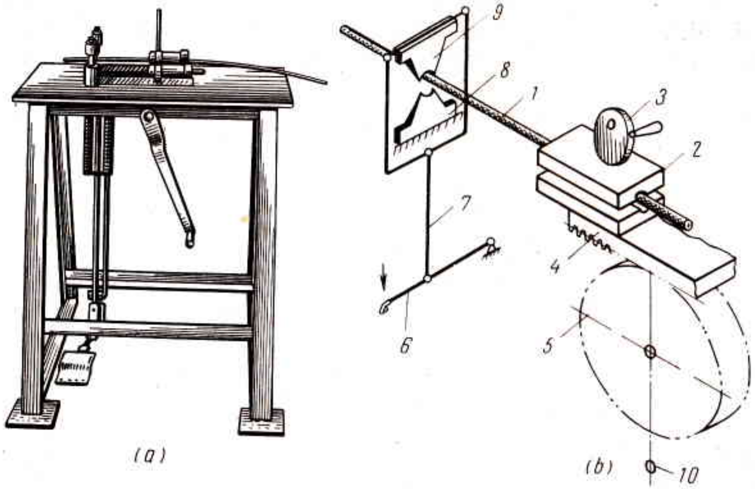


Fig. 124. Paper-insulation stripper:
a—general view; *b*—diagram; *1*—lead; *2*—jaws; *3*—eccentric; *4*—rack; *5*—pinion; *6*—foot-pedal; *7*—link; *8*—bottom blade; *9*—top blade; *10*—handle

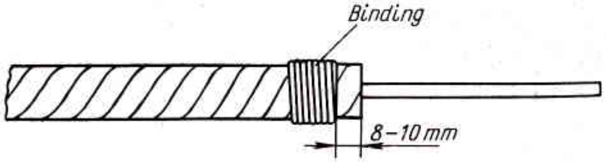


Fig. 125. Skinned wire

The ends of the leads to be connected to bushing terminals or tapping-switch studs should be tinned by a galvanic process and bent into loops in a special tool. The looping tool (Fig. 126) consists of a steel baseplate *1* with a longitudinal groove for the wire to be looped and a cross groove where the mandrel over which loops are made goes in; a lever *2* attached to the baseplate; and a mandrel *3* screwed into the lever. The outside diameter should correspond to the inside diameter of the loop to be made.

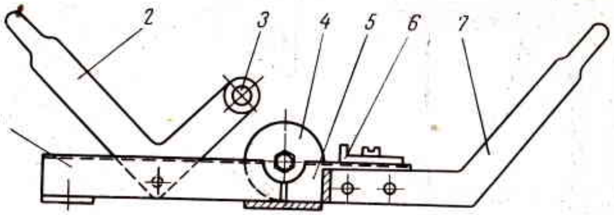


Fig. 126. Looping tool:
1—grooved baseplate; *2*—lever; *3*—mandrel; *4*—bracket; *5*—strip; *6*—limit stop; *7*—lever

The wire is placed in the groove of the baseplate as far as the limit stop *6*. The lever carrying the mandrel is pushed down as far as it will go, and the wire is bent into a half-loop. The other lever *7* is pulled to complete the loop (Fig. 127).

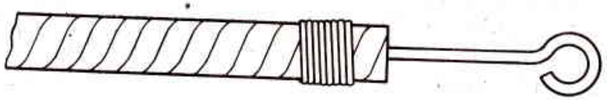


Fig. 127. Wire with its end looped

The looped end of the lead is then given an *expansion bend* (Fig. 128). The expansion bend makes up for variations in the height of the tank and protects the leads from breakage in transit.

Assembly of the Leads. The leads fully assembled on a Size 1 transformer are shown in Fig. 129. The procedure for their assembly is this. The tapping switch *2* is mounted

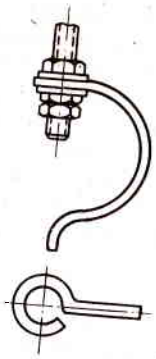


Fig. 128. Use of expansion bends on leads

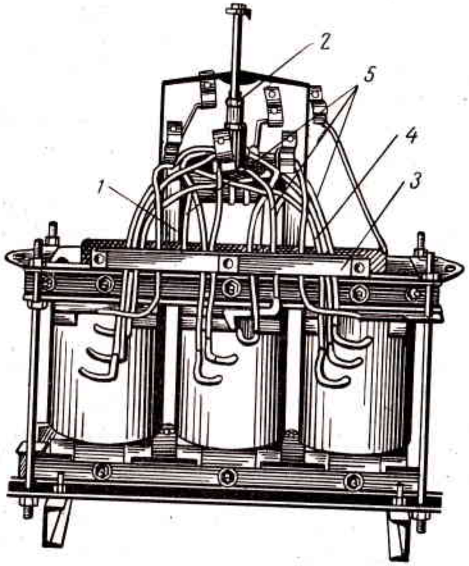


Fig. 129. Lead arrangement on a Size 1 transformer:
1—steel bracket to mount tapping switch; *2*—tapping switch; *3*—beechwood cleat for H.V. leads; *4*—voltage control taps; *5*—leads to terminals *A*, *B* and *C*

on steel brackets *1* bolted to the top yoke clamps. The leads are then connected to the terminal studs of the tapping switch. Next beechwood cleats *3* are fastened to the top yoke clamps and the leads from the tapping switch and also the line leads *A*, *B* and *C*, all bent to drawing, are braced between the cleats.

Each lead or a group of leads is additionally insulated with several strips of cable paper of a width equal to the height of the beechwood cleats plus 10 mm. The insulation should extend the same distance on either side of the cleats clamping the leads.

Now the ends and voltage tappings of the H.V. winding are skinned, and to each of them a line or tapping lead is run, and surplus length is cut off. The connections are made according to the connection diagram, and the joints are welded with a carbon electrode. The welded joints are then scraped bright and insulated.

55. Assembly of H.V. Leads on Size 2, 6-10-kV Transformers

The H.V. windings in Size 2, 6-10-kV transformers are also star-connected. Since, however, the core-coil unit is attached to the tank cover, the tapping switch giving a voltage variation of ±5 per cent is mounted on the tank cover. The tapping switch is of the nine-terminal neutral-point variety.

The leads are made from Grade ПБ wire 2.44 mm in diameter as described in the preceding section. Where connections are to be made to wire 3.05 mm and over in diameter or to the terminal studs of the tapping switch, flexible connectors are soldered to the leads.

The arrangement of the leads is shown in Fig. 130. The following procedure may be recommended for their assembly. First beechwood cleats *2* and *3* are fastened to the yoke clamps. Then the leads are clamped in the cleats to the dimensions specified. The ends of the line leads *A*, *B* and *C* are clamped in cleats *4* and *5*.

Lead assembly drawings should specify the distance *K*, i.e., the distance from the contact of a lead to the nearest fixed structural part. The distance *K* is usually measured from the flange of the top yoke clamp. Each lead or a group of leads is additionally insulated with several strips of cable

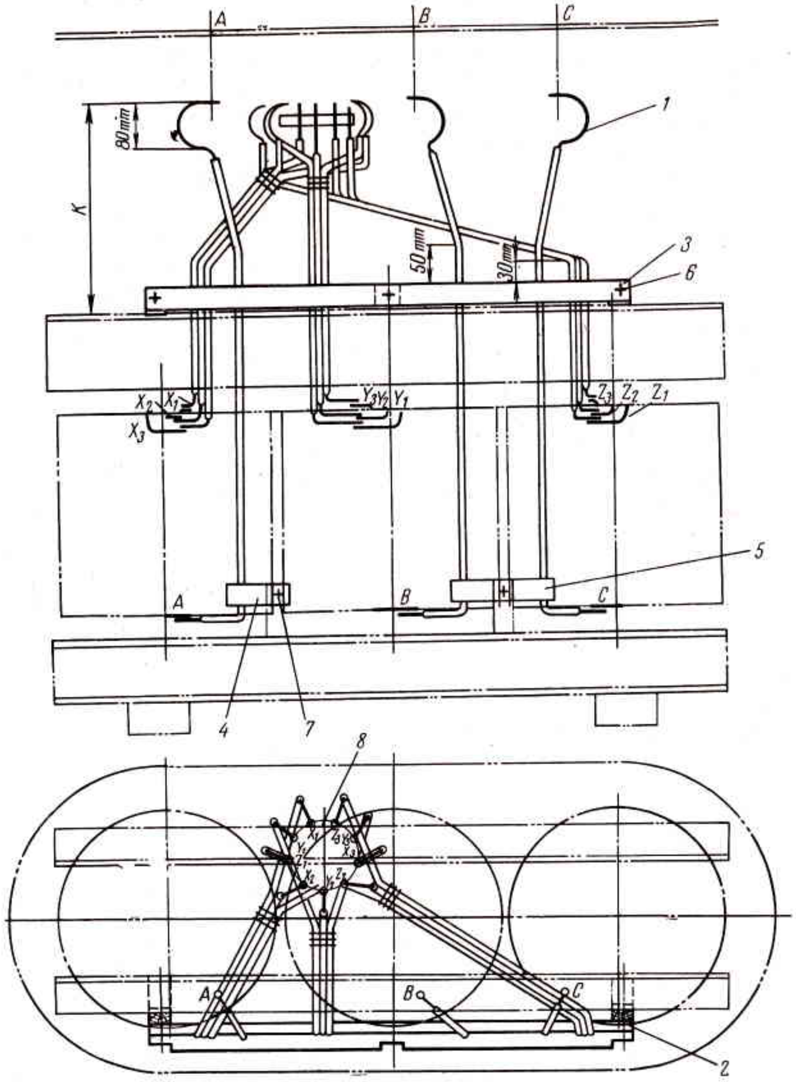


Fig. 130. Arrangement of H.V. leads on a Size 2 transformer:
1—Grade ПБ wire; *2*, *3*, *4* and *5*—beechwood cleats; *6* and *7*—steel bolts; *8*—tapping switch

paper of a width equal to the height of the beechwood cleats plus 10 mm.

During assembly the leads have to be given two or three bends. This should be done with care. The bends should be made to a radius equal to from six to ten diameters of the insulated wire, so as not to damage the insulation.

Then the tappings and winding ends are thoroughly stripped of insulation and varnish, and to each of them the respective leads are run, and surplus length is cut off with cutting pliers.

The connections are made by either arc welding or electric brazing, depending on the size of wire. Joints on wire 2.44 mm in diameter are welded, and those on heavier wire are brazed. The welded or brazed joints are brushed and filed to remove sharp projections, surplus solder and scale. This should be done while the joint is hot. The joints are then insulated, while the tappings of each phase are also banded with cotton tape.

The leads should be insulated from the beechwood cleats with cable paper of a width equal to the height of the cleats plus 10 mm. The insulation should extend an equal distance on either side of the cleats.

56. Assembly of H.V. Leads on Size 3, 35-kV Transformers

In Size 3, 35-kV transformers in which the core-coil unit is attached to the tank cover, the H.V. windings are usually connected in a star. Voltage variation within ±5 per cent is obtained by means of a 12-terminal, 3-position tapping switch. The switch is mounted on the cover.

The ±5 per cent tap is obtained by making common the terminals A_2A_3, B_2B_3 and C_2C_3; the "normal" tap by making common the terminals A_3A_4, B_3B_4 and C_3C_4; and the −5 per cent tap by making common the terminals A_4A_5, B_4B_5 and C_4C_5.

Manufacture of the Leads. The leads are made from Grade ПБ insulated wire from 4.1 to 5.5 mm in diameter, depending on current. Their length is usually given in the table of dimensions in the lead assembly drawing. To keep the paper insulation intact, a wrapping of twisted brown thread is applied over it after the wire has been skinned, as described in Sec. 54. The leads to be taken to the tapping switch are skinned for a distance of 130 mm, and the line leads *A*, *B* and *C* for a distance of 150 mm from the end. The insulation is removed on the stripper shown in Fig. 124.

Then the leads are fitted with flexible connectors for connection to the terminal studs of the tapping switch and the terminal bushings. The flexible connectors are joined by electric brazing on a portable brazing unit. The contact (tinned) surface of the connector and the paper insulation on the lead next to the joint are packed around with wet asbestos to protect them from injury.

The leads are additionally insulated with synthetic-resin-bonded paper tubes with a wall thickness of 2 mm or 4 mm. The tubes are cut on a circular saw into the lengths specified in the lead assembly drawing.

For convenience in joining up paper tubes (where several used on the same lead) and also to make the insulation at the joint reliable, tubes with a wall thickness of over 2 mm are chamfered by turning on a fixture clamped in the chuck of a re-modelled drilling machine or a turret lathe.

Assembly of the Leads. The arrangement of the H.V. leads is shown in Fig. 131. Instead of a common neutral wire, there are two short links (*XY* and *YZ*) between two adjacent phases. These links are to be installed first.

To do this, the last turns of the windings of phases *A* and *C*, skinned of varnish and insulation, are taken to the ends of the split phase *B*. The joints are made so that they are set off at least 40 mm from the axes of the tie-rods of the core. Surplus length is trimmed off, the ends are joined together, and the joints are electric-brazed with portable tongs. The brazed joints are cleaned and insulated with cringed paper or varnished cloth. Next vertical and horizontal beechwood cleats (*6* through *10* and *16* through *21* in Fig. 131) are fastened to the top yoke clamp and to each other by steel bolts *13* and nuts *12*, except for the cleats *20* and *21* which use beechwood dowels *14* and *15*.

On the frame thus formed synthetic-resin-bonded paper tubes *5* are mounted to the drawing. Where a single tube will not be long enough to insulate a lead, two tubes placed one above the other are used. The joint between the two tubes should be at least 25 mm away from a beechwood cleat and not less than 50 mm from similar joints between other pairs of tubes.

The additional synthetic-resin-bonded paper tubes are slipped over the leads, the leads are bent to shape as specified in the drawing and are carried through the tubes *5* clamped in the cleats *6*, *7*, *10* and *21*.

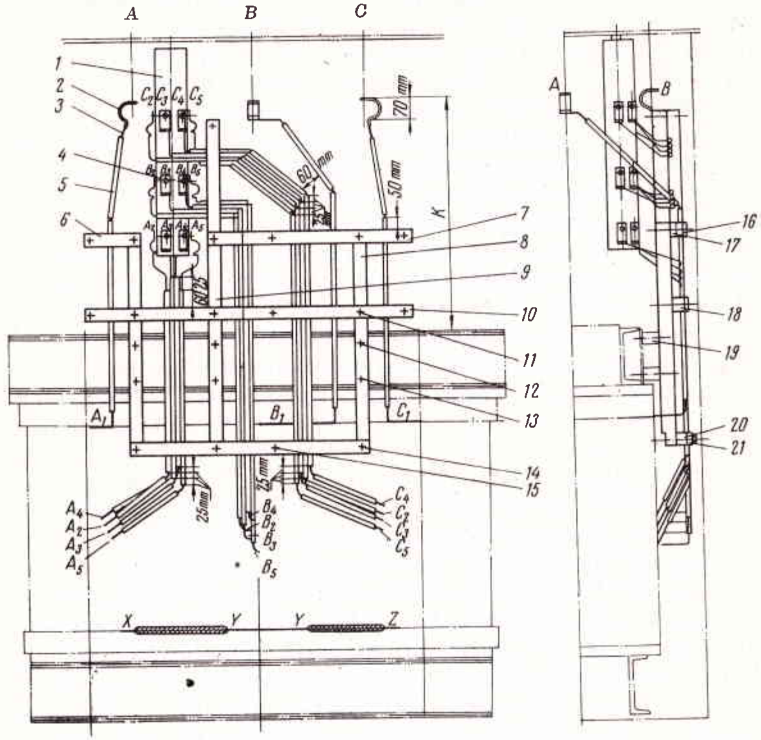


Fig. 131. Arrangement of leads on a Size 3 transformer:

1—tapping switch; *2*—line-lead flexible connector; *3*—Grade ПБ wire; *4*—voltage-control tap flexible connector; *5*—synthetic-resin-bonded paper tubes; *6*, *7*, *8*, *9*, *10* and *16*, *17*, *18*, *19*, *20*, *21*—beechwood cleats; *11*—steel washer; *12*—steel nut; *13*—steel bolt; *14* and *15*—beechwood dowels

The leads should be installed so that ample length is left to carry them to the terminal bushings and the terminal studs of the tapping switch. Therefore, lead assembly drawings always give the distance *K*, i.e., the distance from the contact of a lead to the nearest fixed structural part. This distance is usually measured from the top beechwood cleat or the top yoke clamp.

Now the winding ends and tappings are skinned, cleaned, trimmed with hand-operated cable shears (Fig. 132), bent to the requisite shape, and to each of them the respective leads are joined with portable electric brazing tongs. While the joints are hot, any sharp projections are smoothed down with a file. During the brazing operation the winding and insulation of the core-coil assembly should be covered with sheets of pressboard as a protection against splashes of molten solder.

The joints on the 35-kV leads should be insulated with particular care.

57. Assembly of L.V. Leads on Size 1 Transformers

The L.V. windings of Size 1 transformers in which the core-coil assembly is not attached to the tank cover are usually connected in a star with the neutral point brought out.

In transformers in sizes not over 100 kilovolt-amperes the winding ends serve at the same time as leads. For termination, the winding ends are bent at right angles where they emerge from beneath the top yoke clamp, using an elliptical tube, and brought out with pliers on either side of the yoke studs so that they will not interfere with the clamping of the top yoke and there will be ample clearance to these studs and to the top end of the H.V. winding.

The leads are clamped in the beechwood cleats attached to the top yoke clamp. Each lead is insulated from the cleats with cable paper of a width equal to the height of the cleats plus 10 mm. Then the leads are straightened, bent with an elliptical steel pipe and pliers and connected as required.

The line leads *a*, *b*, *c* and *0* are connected to the bushing terminals by means of flexible connectors soldered to the leads.

The leads should be installed so that ample length is left to carry them to the bushing terminals. Therefore, as

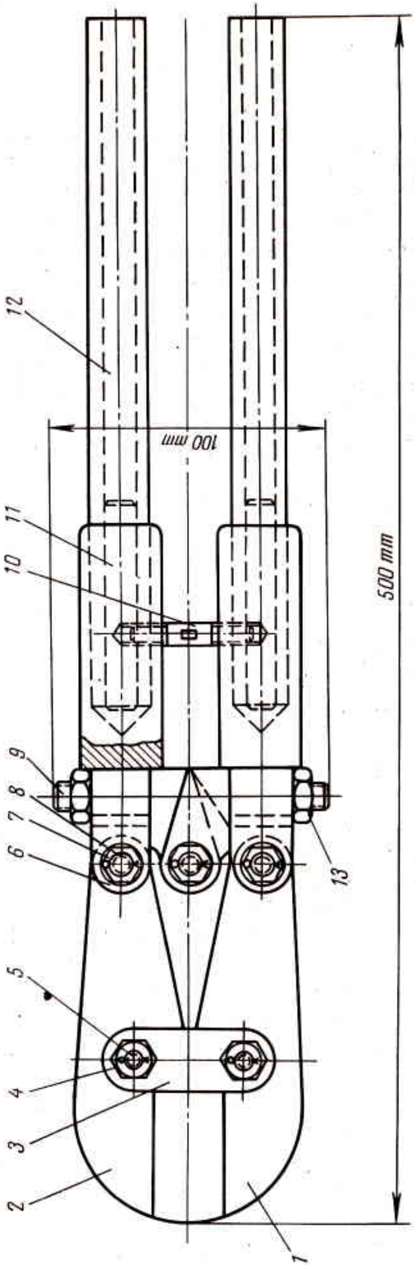


Fig. 132. Hand-operated cable shears:

1—bottom blade; 2—top blade; 3—steel strip; 4, 7 and 13—steel nuts; 5 and 8—steel pins; 6—fork; 9—shoe; 10—limit dowel; 11—stud; 12—tube

stated earlier, lead assembly drawings specify the distance from the contact of each lead to the nearest fixed structural part, usually to the flange of the top yoke clamp.

58. *Assembly of L.V. Leads on Size 2 Transformers*

The L.V. windings of Size 2 transformers in which the core-coil unit is attached to the tank cover are connected in a star with the neutral point brought out. The assembly of the leads in their case is handicapped by the fact that the L.V. windings are usually wound with a large number of parallel conductors. After the assembly of the core-coil unit the conductors in the winding ends are left bent and spread in all directions.

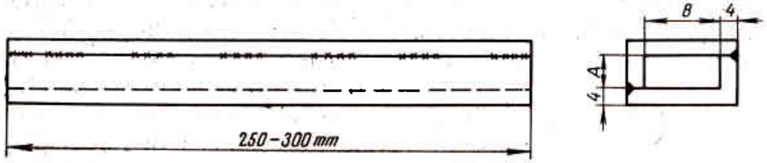


Fig. 133. Bunching box

Therefore, before the leads can be assembled, the winding ends should be bunched and arranged in a common horizontal plane by means of a bunching box, such as shown in Fig. 133.

The bunching box should be large enough to accommodate all of the conductors. As a rule, the depth *A* of the box is made greater than the height of the wire, and the width *B* is 5 mm greater than the thickness of a winding turn, i.e., the aggregate thickness of the bunched wires. The length of the box is anywhere from 250 to 300 mm. The actual dimensions of bunching boxes vary from transformer to transformer, since transformers of different capacities use different conductor sizes.

Prior to bunching, the winding ends are straightened with a hammer on a portable steel block. First some of the wires in the bunch are laid in the box and straightened in a common plane. Then the remaining wires are driven by hammer blows towards the box and threaded into the box. Now the box is moved to where the conductors branch off from the winding, and the conductors are bent with an adjustable spanner to the drawing. In doing so, it is essential to maintain the specified clearances to the top yoke bolts.

The winding ends are secured in the beechwood cleats fastened to the top yoke clamp. Using the same fixtures, the winding ends are bent for connection to the line leads and into a star.

The length of the conductors is measured off either to a template or as required by the actual arrangement. Surplus length is trimmed off with hand shears (Fig. 132). In order that loose ends will not get into the winding, the wires are first cut halfway through their diameter, the workman takes the nicked conductors with one hand and the nearly closed blades of the shears with the other and cuts off the wires. The cut-off ends should be put into a wastes box.

Then the leads made in advance are placed in the requisite positions, and the winding ends are bent and laid so that they touch the bar leads over the entire surface. If there is a notch in the bar lead, the winding ends should be divided into two equal groups and each group laid on either side of the notch. This will keep the joint uniformly heated in brazing.

For convenience the tongs should be put on the rack (Fig. 99) set to the requisite height. The joint is reliably clamped between the electrodes of the tongs, current is turned on, the joint is heated and brazed. The finished joint should be thoroughly cleaned and filed (usually while it is hot). Each joint should be insulated from the beechwood cleats with a length of pressboard 0.5 mm thick or with a length of cable paper of a width equal to the height of the cleats plus 10 mm. The insulation should extend the same distance on either side of the cleats.

59. *Assembly of L.V. Leads on Size 3 Transformers*

The L.V. windings of Size 3 transformers in which the core-coil unit is attached to the tank cover are usually delta-connected. The assembly of the L.V. leads on Size 3 transformers is a more complicated operation. Their arrangement is shown in Fig. 134.

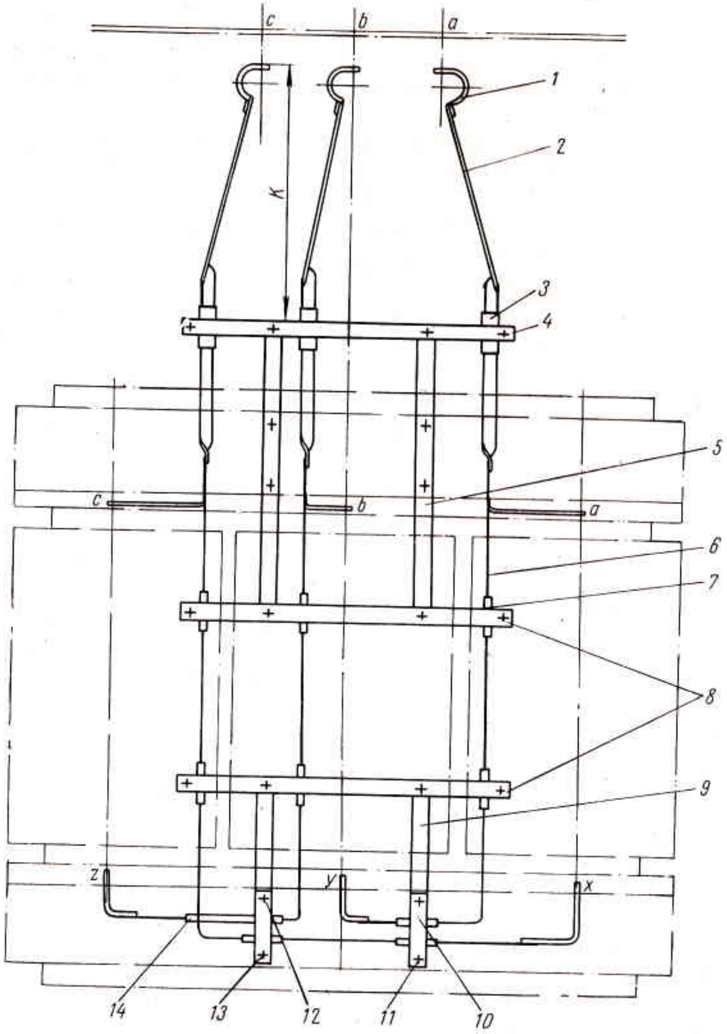


Fig. 134. Arrangement of L.V. leads on a Size 3 transformer:

1—flexible connector; *2*—L.V. line lead; *3*—pressboard wrap; *4*, *5*, *8*, *9* and *10*—beechwood cleats; *6*—copper wire; *7* and *14*—synthetic-resin-bonded paper tubes; *11*—steel bolt; *12*—steel nut; *13*—steel washer

The first step is to install vertical and horizontal beechwood cleats *4*, *5*, *8*, *9* and *10* on the top and bottom yoke clamps. The cleats are fastened to the yoke clamps and to each other by steel bolts *11*. The bolt heads are placed on the clamp side and the steel washers *13* and nuts *12* on the cleat side.

Now the line leads *2* made in advance are clamped in the top horizontal cleats *4*. Each lead should be insulated from the beechwood cleats with a pressboard wrap *3*. The leads should be installed so that ample length is left for connection to the terminal bushings. The length (distance *K*) is ordinarily given in the lead assembly drawing, as measured from the nearest beechwood cleat on the top yoke clamp or on the vertical strips. In Fig. 134 this distance is measured from cleat *4*. The leads are first fastened to this cleat after the distance *K* has been adjusted and verified. Thus the correct arrangement of leads depends on whether the distance *K* has been correctly measured for each lead extending from the reference cleat.

At the same time the delta-connection leads are clamped in the cleats *5*, *8*, *9* and *10*. Each lead should be insulated from the cleats with synthetic-resin-bonded paper tubes *7* or *14*. The tubes *7* should extend the same distance on either side of the cleats.

The winding wires are next straightened with a hammer on a portable steel block and are bent with a bunching box and an adjustable spanner for joining as shown in the drawing. The ends of the conductors should be thoroughly cleaned and excess length trimmed off.

The line lead made from copper bar, the delta-connection lead made from round copper wire and the ends of the winding conductors are prepared for electric brazing as shown in Fig. 94.

The joints are made with portable electric brazing tongs. The joint to be made is clamped between the electrodes of the tongs, the foot-pedal switch is pressed to energize the transformer, and the joint is raised to the melting point of the solder. This temperature is maintained until the joint is fully filled with solder. Then the transformer is switched off, the tongs are removed, and sharp projections at the joint are smoothed down with a file while the joint is still hot.

60. *Assembly of Leads on the Type ATMK-100/0.5 Moving-coil Voltage Regulator*

The arrangement of the leads on the Type ATMK-100/0.5 moving-coil voltage regulator is diagrammatically shown in Fig. 135. If the coils of the regulator are wound with aluminium wire, the leads are also usually made of round aluminium conductors. For connection to the terminal bushings, the leads are fitted with terminal lugs made of copper angles or plates (see Fig. 121).

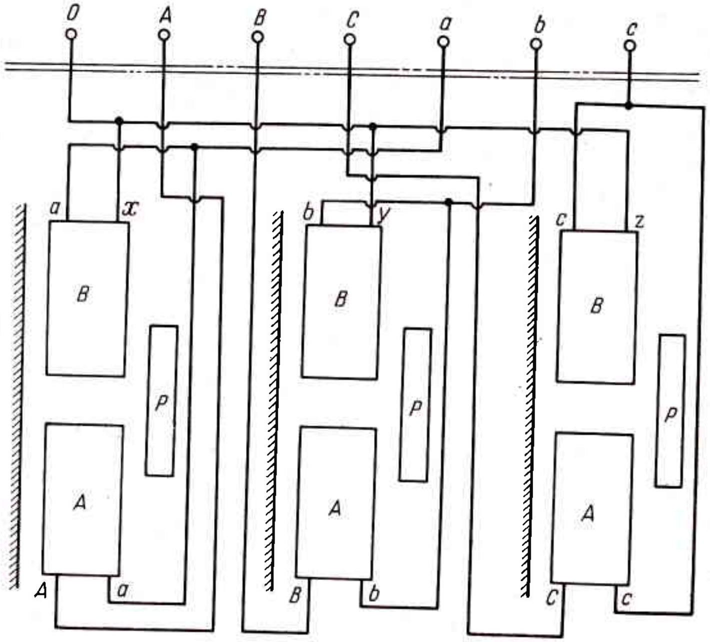


Fig. 135. Diagram showing connections of the leads in Type ATMK-100/0.5 moving-coil voltage regulator

The first step in the assembly of the leads on the regulator is to mount the terminal bushings on the tank cover which also serves as the top plate of the operating mechanism (see Fig. 91).

The sequence of operations for the installation of the built-up terminal bushings (see Fig. 55) is this. First, a rubber washer *9* is put on the terminal *1* to which a square steel nut *10* is welded. Then the terminal and washer are inserted into the hole of the bottom shell *6* of the bushing so that the washer *9* and nut *10* fit into the recess. Now another washer *8* is placed on the bottom shell of the bushing, and the bottom shell together with the terminal are inserted into the hole in the tank cover.

At the same time a pressboard washer *7* is placed on the tank cover from the opposite side, and the top shell *5* of the bushing is mounted. Next a pressboard washer *4* and a copper washer *3* are put on the end of the top shell of the bushing, and the bushing is clamped together by turning the nut on the terminal with a spanner. The procedure is the same for all of the terminal bushings.

After all the terminal bushings have been mounted, the leads can be assembled. The arrangement of the leads is shown in Fig. 136. The following procedure may be recommended for their assembly.

First, the leads *7*, *8*, *9* and *15* are mounted and connected to the terminal bushings *A*, *B*, *C* and *0*. Then the leads *7*, *8* and *9* are fastened. On the bottom plate of the operating mechanism the leads are clamped between beechwood cleats *1* and spacers *3* by bolts *2*. The lead *15* is fastened on the tank cover between a beechwood cleat *10* and a spacer *11* by bolts *17*.

The leads *12*, *13* and *14* are connected to the terminals *a*, *b* and *c* and clamped in beechwood cleats *1* and *3* by bolts *2* on the top and bottom plates of the operating-mechanism frame. The synthetic-resin-bonded paper tubes *16* should extend the same distance on either side of the beechwood cleats. To keep the bolts from working loose in service, they are locked by spring washers *5* placed in addition to steel washers *4*.

The way the leads are clamped in beechwood cleats is shown in Fig. 137. The cleats have recesses of a width corresponding to the outside diameter of the synthetic-resin-bonded paper tubes.

Now the winding ends and leads are prepared for joining. The winding conductors are bent to drawing, their ends are

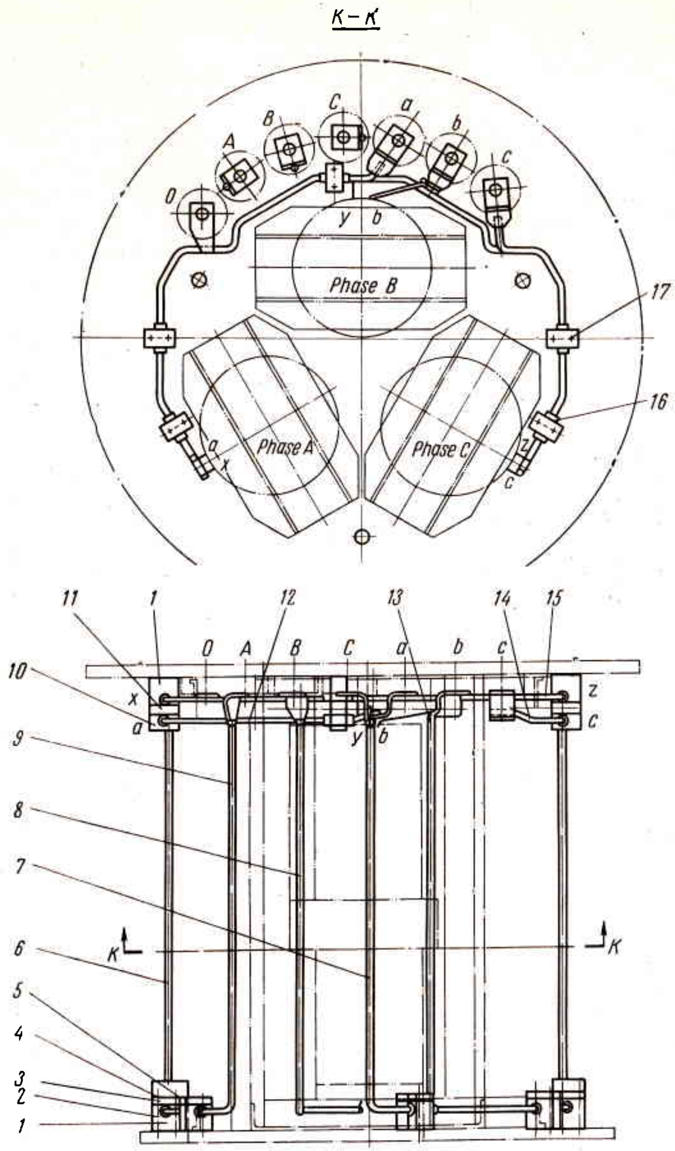
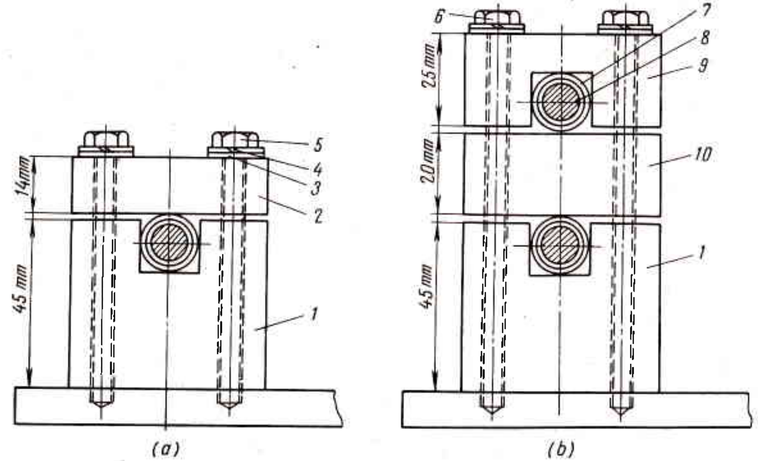


Fig. 136. Arrangement of leads on Type ATMK-100/0.5 moving-coil voltage regulator:

1—beechwood cleat; *2*—steel bolt; *3*—beechwood spacer; *4*—steel washer; *5*—spring washer; *6*—connecting lead; *7*—lead *C*; *8*—lead *B*; *9*—lead *A*; *10*—beechwood cleat; *11*—beechwood spacer; *12*—lead *a*; *13*—lead *b*; *14*—lead *c*; *15*—lead *0*; *16*—synthetic-resin-bonded paper tube; *17*—steel bolt

thoroughly cleaned, and surplus length is trimmed off. The leads are carried to the respective winding ends, and surplus length is also trimmed off. The joints between the leads and winding conductors are degreased with aviation spirit or acetone and welded by the argon-shielded welding process. The welded joints are filed to remove sharp projections and scale. The joints between the leads and the winding ends A, B and C are banded with linen-finished tape, while the joints between the leads and the winding ends a, b, c, x, y and 0 are insulated with two layers of half-lapped varnished cloth and banded with linen-finished tape.



(a) (b)

Fig. 137. Clamping the leads of a moving-coil voltage regulator in beechwood cleats:

a—to bottom plate of operating mechanism; *b*—to top plate of operating mechanism; *1*—beechwood cleat; *2*—beechwood spacer; *3*—steel washer; *4*—spring washer; *5*—steel bolt; *6*—steel bolt; *7*—synthetic-resin-bonded paper tube; *8*—aluminium lead; *9*—beechwood cleat; *10*—beechwood spacer

61. *Insulation of Leads*

After the leads have been assembled and all the joints brazed or welded, the leads should be insulated. This is a simple operation which does not call for very skilled labour. Yet, it must be done carefully. The leads should be insulated with varnished cloth and also with cable or cringed paper. The thickness and material of the insulation are usually specified in the lead assembly drawing.

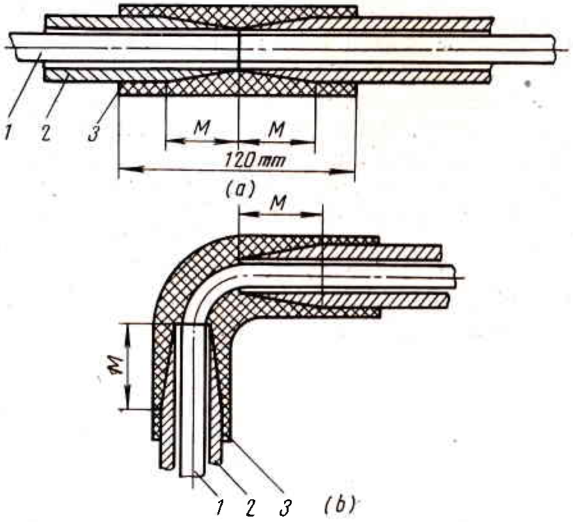


Fig. 138. Insulating the joint between two synthetic-resin-bonded tubes:

a—straight joint; *b*—angle joint; *1*—wire; *2*—synthetic-resin-bonded tube; *3*—joint insulation

The insulation is applied to form a half-lap. Strips of varnished cloth or paper should be up to 30 mm wide. The insulation should be applied in tightly fitting layers, smoothing down every next layer to the previous one. There should be neither folds nor voids between the layers. The thickness of the insulation should be checked with a gauge with a hole of the respective diameter. The joints between the synthetic-resin-bonded paper tubes slipped over the 35-kV leads should be insulated with strips of cringed or cable paper, Fig. 138 (*a*).

Where tubes are joined at an angle, they should be moved as close as possible to the bend on the conductor, Fig. 138 (*b*).

The length of the chamfered portion, M, should be 30 mm for tubes with a wall thickness of 4 mm and 40 mm for tubes with a wall thickness of 6 mm. The length of the insulated portion should be 4 mm greater than the diameter of the tube.

In the case of leads made from Grade ПБ insulated wire, only soldered or brazed joints should be insulated.

To keep the insulation tightly wound, the insulated areas are banded with one layer of half-lapped linen-finished tape 20 to 25 mm wide. If the insulation is not sufficiently thick or is loosely wrapped, a puncture may take place.

Leads made of bare round wire or copper bar are given a coat of ГФ-95 alkyd varnish or No. 138 primer for their whole length except the contact surfaces. The insulated areas are painted all over. Prior to the application of the varnish, the conductors should be degreased by rubbing them with waste moistened with a solvent.

Chapter

6 The Drying of the Core-coil Assembly

62. General

The solid insulation of the core-coil assembly is mainly made of hygroscopic fibrous materials (pressboard, paper, wood). Although advantageous in many respects, which is the reason why they are widely used in transformer manufacture, these materials suffer from a major drawback; they readily pick up moisture from the surroundings, which fact appreciably impairs their insulating qualities.

By way of example, the breakdown voltage of a well-dried pressboard 2 mm thick is about 24 kilovolts. When the same pressboard carries 6.5 per cent moisture, the breakdown voltage drops to as low as 18 kilovolts. When the moisture content rises to 10 per cent, which is the limit stipulated by the relevant standard, the electric strength of pressboard is reduced to 13 kilovolts, which is only slightly more than half the electric strength of dry pressboard. Other fibrous materials behave similarly.

In order to drive off moisture from the solid insulation and to give it high electric strength, the core-coil assembly of a transformer is dried. On drying, the moisture moves from inside the material to the surface from where it goes into the surrounding air.

The transfer of moisture from the surface of a material into the surrounding air is due to the difference in vapour pressure between the surface of the material and the surroundings. The rate of moisture transfer from the surface of a material increases as the difference in vapour pressure increases. Therefore, for rapid drying it is essential to keep down the vapour pressure in the surroundings (i.e., in the drying oven) and to raise it on the surface of the material. The first requirement is satisfied by maintaining a vacuum in the drying oven, and the second by heating the core-coil assembly.

If we measure the moisture content in the various materials used as insulation in the core-coil assembly in the course of drying and relate the results to time, we shall obtain the drying chart of Fig. 139. The curve in the chart has two distinctive regions. In the region *AB* the moisture content varies but little, because at the beginning of the drying operation the damp materials are being heated and their temperature is not yet sufficient to cause the moisture to move to the surface of the material and into the surrounding air at a high rate.

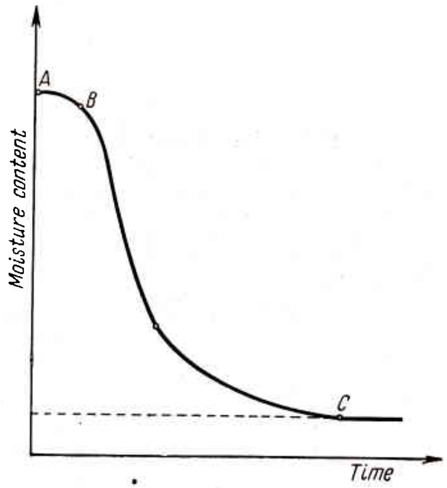


Fig. 139. Drying chart for a fibrous material (moisture content related to drying time)

In the region *BC*, the actual drying takes place. At first the moisture content diminishes at a high rate; then the rate slows down. At point *C* the drying is completed, because the material has the same moisture content as the surroundings

(shown by the dotted line). In other words, an equilibrium is reached between the material and the surroundings, and no more moisture can be driven off.

63. Drying Conditions

The conditions for drying the core-coil assembly of Size 1 through 3 transformers vary with their capacity, voltage class and design (the amount of solid insulation used). The drying process is performed in a vacuum-drying oven.

The drying process usually takes 16 to 18 hours to complete and may be divided into three principal stages:

—the temperature inside the oven is raised to a predetermined point;

—the core-coil assembly is heated up;

—the core-coil assembly is dried.

The core-coil assembly has to be heated up in order to make the moisture move from the insulation into the surrounding air. The core-coil assembly placed in a vacuum-drying oven is heated up at 100±10°C. The time required to heat up the core-coil assembly (or several assemblies) depends on its weight (mass), the insulation design and the capacity of the transformer, and varies from transformer to transformer. For Size 1 transformers the heating-up time is 3 hours, for Size 2 and 3 transformers it is 5 hours.

During the heat-up, a vacuum of 200 mm Hg should be maintained in the oven to prevent the moisture from condensing on the core. Some of the moisture is driven off from the insulation. The heat-up is followed by the drying run under vacuum.

The vacuum in the oven is raised to 450 mm Hg over 15 minutes and 720 mm Hg during an hour (the residual pressure in the oven should not exceed 4 mm Hg). At 100±10°C and a vacuum of 720 mm Hg, the moisture is driven off from the heated core-coil assembly at a high rate. Towards the end of the drying run the evolution of moisture ceases. The drying may be stopped if two measurements at one hour's interval show that no more moisture is given up.

During the drying operation, a drying log should be kept where the following data should be entered: the tempera-

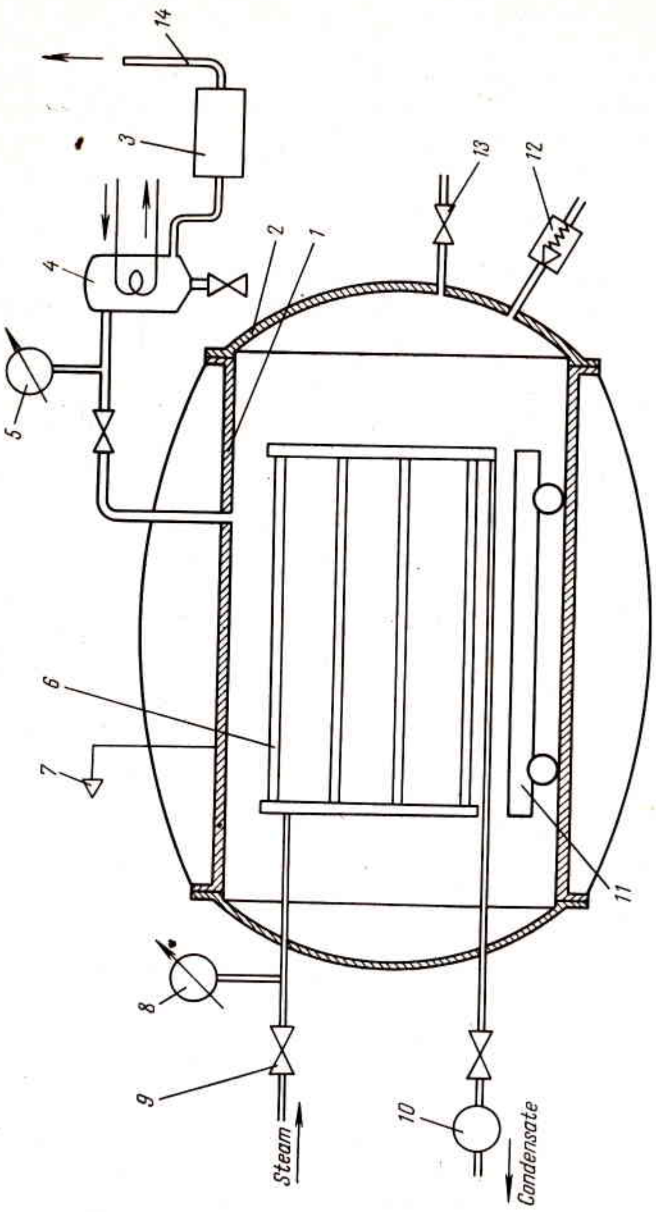


Fig. 140. Horizontal vacuum-drying oven:

1—welded tank; *2*—tank cover; *3*—Type BH-6 vacuum pump; *4*—Type МП-37 condensate chamber; *5*—vacuum gauge; *6*—steam heaters; *7*—remote-indicating thermometer; *8*—pressure gauge; *9*—gate valve; *10*—drip-pot; *11*—truck; *12*—relief valve; *13*—vacuum-release cock; *14*—exhaust pipe

ture in the oven as measured by a temperature indicator, the vapour pressure, the vacuum, and the amount of moisture given up.

During the subsequent assembly the insulation of the core-coil unit inevitably picks up some moisture. If the moisture content is to be kept within safe limits, the core-coil assembly may be held in air for not more than 24 hours in the case of transformers in the 35-kV class and for not more than 48 hours in the 6-10-kV class.

The quality of the insulation in the core-coil assembly is further improved by impregnating it with transformer oil in the tank.

64. Drying Equipment

The assembly shop of a transformer works will usually have several vacuum-drying ovens arranged in a variety of ways. The best arrangement is the horizontal placement of the ovens outside the transformer-assembly line. With this layout, the production (crane-served) area is used for its designated purpose of transformer assembly and the ovens do not interfere with the handling of parts or assembled transformers. Also, the core-coil assembly can be rolled conveniently into the oven on a truck.

A horizontal vacuum-drying oven (Fig. 140) is a welded tank *1* with the framework lagged with graphitized asbestos. The lid *2* is mounted on a fixture by means of which it can be removed from and put on the tank. During operation, the lid is clamped to the tank by swing bolts. The temperature inside the oven is raised to and maintained at 100-110°C by steam heaters arranged on the inside wall and bottom of the oven. On the outside both the tank and lid are lagged with thermal insulation in order to reduce heat loss. Vacuum inside the oven is produced by a Type BH-6 vacuum pump. The condensate is collected in a Type МП-37 chamber set up on a specially designed support.

The progress of drying is monitored by measuring the amount of moisture given up. The vacuum is measured by a vacuum gauge *5* while the temperature is indicated by a remotely indicating thermometer *7*.

Chapter 7 Assembly of Terminal Bushings

65. Bushing Components

Terminal bushings are prepared concurrently with the assembly of the core-coil unit. The terminals are made of round copper bars threaded at both ends. The diameter of the terminal is 12 mm and more, depending on the current for which a given terminal bushing is rated. Terminals with a diameter of 24 mm and over are threaded at one end only. The other end is flattened into a spade lug.

The first step in the assembly of a terminal bushing is to fit out the terminal. To do this, a steel or bronze cap *3* is screwed onto the terminal *1* for a distance given in the drawing, and the cap is locked by a lock-nut *2* (Fig. 141). If a terminal has one end flattened into a spade lug, the cap is put and not screwed onto the terminal, and the length of the projecting end of the terminal is adjusted during the welding operation.

Built-up bushings intended for installation on the wall or cover of the transformer tank have no metal cap. Instead, a steel or copper square nut is screwed onto the terminal. To lock the nut in place, it is struck with a hammer to crush its thread.

The terminal thus fitted out is heated in a gas-fired compartment furnace to 600-700°C, and the cap or nut is welded to the terminal from the inside by the gas-welding process. The filler metal is brass, and the flux is borax calcined for 3 hours at 700°C.

The welded joint is tested for tightness with compressed air on the fixture of Fig. 142. For the test, the terminal, with the cap welded to it, is inserted into the opening of the detachable stage *1*, the cap is placed with its end face onto the rubber ring *2*, and the screw *4* is tightened so that the face of the cap is pressed snugly to the ring. The joint between the cap and the terminal is painted with soapsuds, using a brush *5*, a pressure of at least 1.5 atmospheres is built up inside the cap, and the joint is watched for one minute. If there are no soap bubbles at the joint, the weld is of good quality. In the case of poor welding, the joint is re-welded, and the soapsuds test repeated. Then the terminal and cap are tinned by a galvanic process, and the soapsuds test is applied again.

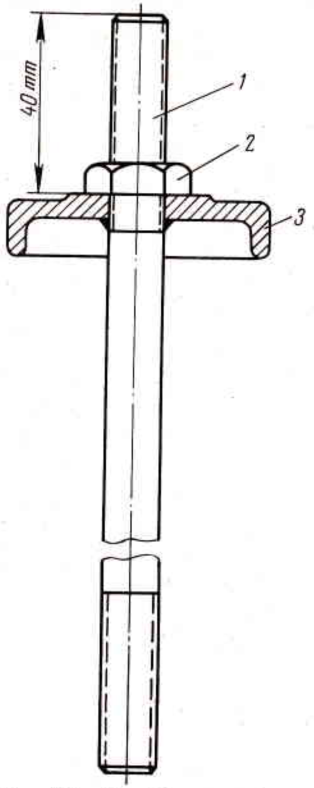


Fig. 141. Bushing terminal and cap:

1 — copper terminal; *2* — lock-nut; *3*—cap

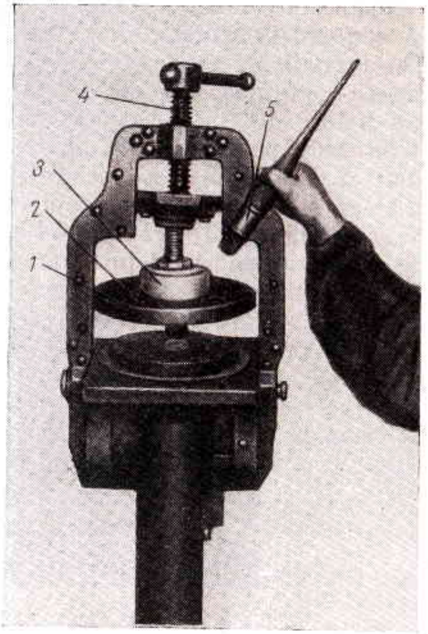


Fig. 142. Fixture to test the weld between the terminal and cap:

1—detachable stage; *2*—rubber ring; *3*—terminal and cap; *4*—screw; *5*—brush

66. Preparation of Magnesia Cement

The porcelain shells or insulators of terminal bushings are bonded to the metal flanges by magnesia cement which produces a strong joint between porcelain and metal. Magnesia cement consists of 36 per cent of caustic magnesite (by weight), 19 per cent of porcelain flour and 45 per cent of a solution of magnesium chloride (sp. gr. 1.2).

Magnesia cement is prepared in a small metal container in a quantity which can be used up in 15 to 20 minutes. The ingredients are thoroughly mixed until a uniform fluid mass is obtained. The cement is poured at a temperature of not below 10°C. The cement sets in about 12 hours after it has been poured at 16°C. The hardened surface is given a coat of Grade 624-C nitrocellulose lacquer.

Magnesite is very hygroscopic. Therefore, if the cement is to be of high quality, it should be calcined at 700° to 750° C for 2.5 hours and kept in a hermetically closed container.

The solution of magnesium chloride is prepared of two parts (by weight) of crushed crystalline magnesium chloride and one part (by weight) of hot water. The mixture is stirred until all of the magnesium chloride is dissolved, and the solution is allowed to settle for five to six hours. If there is much sediment, the solution should be filtered through a piece of gauze and kept in a well-corked glass vessel.

67. Assembly of Indoor 6-kV Terminal Bushings

No special fixtures are required for the assembly of indoor 6-kV terminal bushings. The bushing is mounted on the tank cover on a pressed flange placed on the annular shoulder of the porcelain shell.

The terminal *1*, with a cap *2* welded to it, is clamped in a bench vise (Fig. 143). Then a rubber washer *3* is inserted into the cap, and the porcelain insulator *4* is mounted. The rubber washer reliably seals the joint between the cap and the insulator. Next a pressboard washer and a metal washer are put on the terminal. The washers are topped by a nut which is tightened all the way down.

For pouring magnesia cement, the assembled bushing is placed upright, with the cap down. The cement is poured into the space between the insulator and the cap from a glass ladle. After the cement has been poured, the bushing is left in the upright position for 12 hours until the paste hardens. Surplus cement and overflows are removed, and the hardened surface is given a coat of Grade 624-C nitrocellulose lacquer.

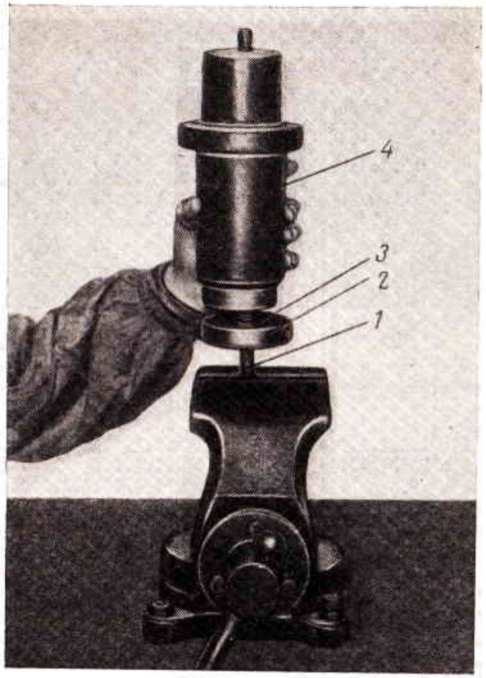


Fig. 143. Assembly of a 6-kV indoor bushing:
1—terminal; *2*—cap; *3*—rubber washer; *4*—porcelain insulator

The terminal is fitted with washers and nuts at both ends for connection of a winding lead to the bushing and of the bushing to the external circuit.

68. *Assembly of Outdoor 35-kV Terminal Bushings*

Outdoor 35-kV terminal bushings are assembled in a special fixture (Fig. 144). In this fixture, bushings can be assembled with high precision and the cap and flange with which the bushing is fastened on the tank cover can be conveniently cemented with magnesia paste.

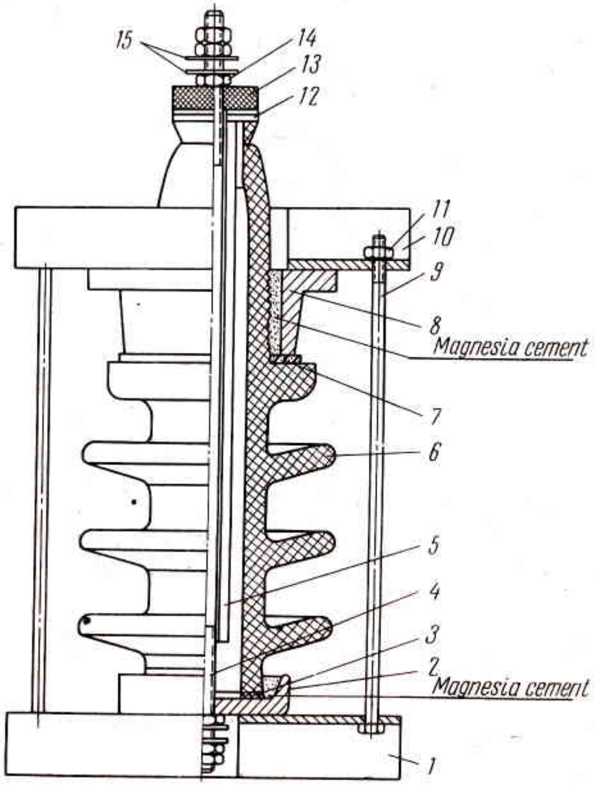


Fig. 144. Assembly of a 35-kV bushing in a fixture:

1—fixture baseplate; *2*—cast-iron cap; *3*—rubber washer; *4*—terminal; *5*—synthetic-resin-bonded paper tube; *6*—porcelain insulator; *7*—rubber gasket; *8*—cast-iron flange; *9*—fixture stud; *10*—fixture top plate; *11*—fixture nut; *12*—notched pressboard washer; *13*—laminated-paper ring; *14*—nut; *15*—washers

For assembly, the terminal *4*, with a cast-iron cap *2* welded to it, is mounted on the baseplate *1* of the fixture. A rubber washer *3* is placed into the cap and a synthetic-resin-bonded paper tube *5* is slipped over the terminal.

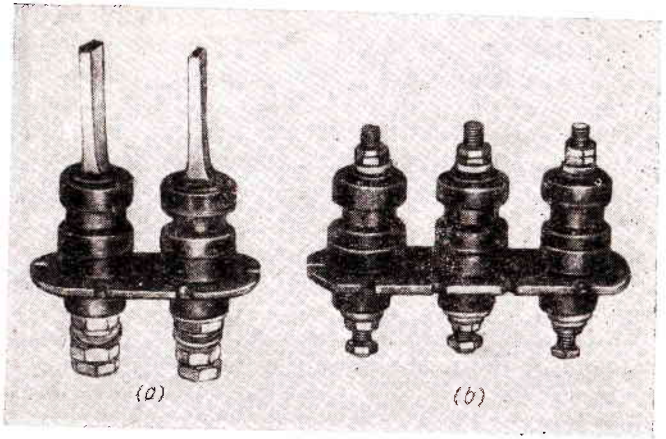


Fig. 145. L.V. bushings in a multiple mounting:
a—double; *b*—triple

Then the porcelain shell *6* is put on the cap, and a pressboard washer is placed on the terminal. The washer has a cut-out which allows oil to flow into the shell. The pressboard washer is topped by a paper-base laminate ring *13*, and the nut *14* is tightened to clamp the bushing assembly together.

The next step is to mount the cast-iron flange *8*. To obtain a well-sealed joint between the insulator and the flange, an annular rubber gasket *7* is put on the shoulder of the shell. The flange is placed with its narrow end to the gasket. Now the studs *9* and nuts *11* are tightened to clamp the flange to the rubber gasket by the top plate *10* of the fixture. As a result, the bushing is brought into a precisely upright position. It is essential that the gap between the shell and the flange be uniform all the way round the circumference. Then this gap and the space between the shell and the cap are filled with magnesia cement.

For good results, the paste should be poured in a thin jet, giving it enough time to spread evenly in the annular gap. The pouring, once started, should never be interrupted, nor paste from different batches used. The paste should be prepared in a quantity sufficient for a complete fill.

After pouring the paste, the bushing should be allowed to stay in the upright position for 12 hours. Then surplus paste and overflows are removed, and the hardened surface is given a coat of Grade 624-C nitrocellulose lacquer.

Now the nuts *14* and washers *15* are put on the top and bottom ends of the terminal for connection of a lead to the bushing and of the bushing to the external circuit.

69. Assembly of Terminal Bushings on a Multiple Mounting

L.V. terminal bushings for 800-1,400 amperes, both indoor and outdoor, are usually set up in double or triple mountings (Fig. 145). The procedure is the same as in the previous case, but greater care must be exercised. The terminal bushings set up in the same mounting should be equally spaced apart, and their terminals or spade lugs should run parallel to each other.

Chapter

8 Finishing and Tanking Operations (Stage Three)

70. General

After it has been dried, the core-coil unit comes in for the third stage of transformer assembly. In the third stage, it is finished and finally clamped, the tank cover is fitted out with accessories and mounted on the transformer, the terminal bushings are mounted, the leads are connected to the terminal bushings and the tapping switch, the core-coil unit is lowered into the tank, the cover is bolted down, and the transformer is filled with oil. Now the transformer is ready for testing and final finishing.

Because of the great variety of transformer types and modifications, a detailed discussion of the tanking operation as carried out on all Size 1 through 3 transformers is obviously an unattainable thing. Fortunately enough, they have many features in common, and for the purpose of discussion they may be divided into three general groups.

The first group embraces Size 1 transformers in which the core-coil assembly is not attached to the tank cover. Other Size 1 transformers and also Size 2 and 3 units in which the core-coil assembly is attached to the tank cover by the lifting rods may be placed in the second group. To the third group belong Type ATMK-100/0.5 moving-coil voltage regulators. The operations common to all of the various groups are described only once.

Tanking is performed to the assembly and outline drawings of transformers.

71. Painting of the Tank, Cover and Conservator

Good paintwork goes a long way towards preventing corrosion. This is why special care must be exercised when painting the tank, cover and conservator of a transformer.

Paint can be applied by any of the three following methods: by spraying, by flowing, and by dipping. Spraying is the most commonly used of the three. The tool is a spray gun operating on compressed air under a pressure of 3 to 6 atmospheres (gauge). Spraying offers high speed and good surface coverage.

Fig. 146 shows a spraying outfit used where painting has to be done on a large scale. It consists of a spray gun *7*, a pressure tank *1*, and oil trap *16*, a paint hose *6*, and air hoses *9*, *10* and *20*.

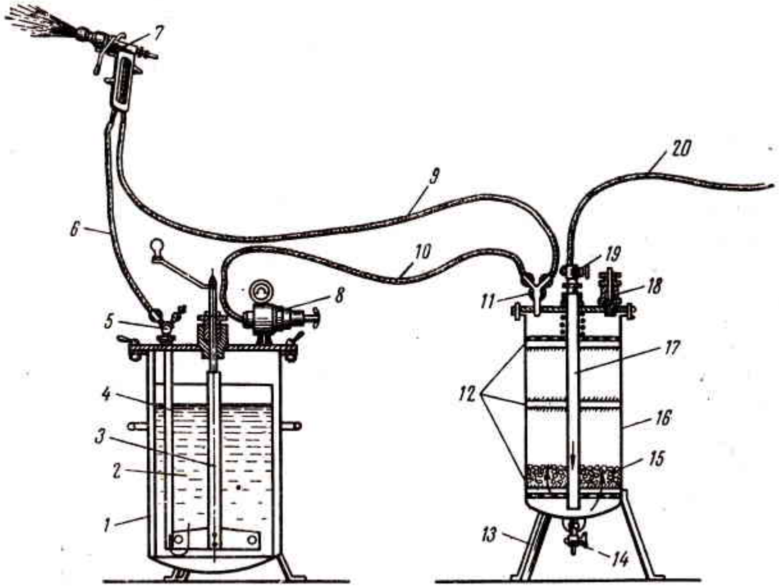


Fig. 146. Spraying outfit incorporating a pressure tank:

1—paint-pressure tank; *2*—paint bucket; *3*—stirrer; *4* and *17*—tubes; *5* and *18*—relief valves; *6*—paint hose; *7*—spray gun; *8*—pressure regulator; *9*, *10* and *20*—air hoses; *11* and *19*—air cocks; *12*—felt gaskets; *13*—leg; *14*—drain cock; *15*—coke; *16*—oil trap

The oil trap serves to remove water and oil from the air supplied under pressure from the mains over the hose *20*. When the cock *19* is open, compressed air flows through a

tube *17* into the bottom portion of the oil trap, passes through a filter (which consists of a bed of coke *15* and felt disks *12*), a pressure regulator *8* fitted with a pressure gauge, the hoses *9* and *10*, the pressure tank and into the spray gun. The oil trap is mounted on legs standing on the floor and has a relief valve *18* and a drain cock *14* to drain oil and water.

The pressure tank is a container fitted with a lid clamped to it by swing bolts. The container houses a bucket *2* for paint. The compressed air entering the tank through the pressure regulator forces the paint from the bucket into the

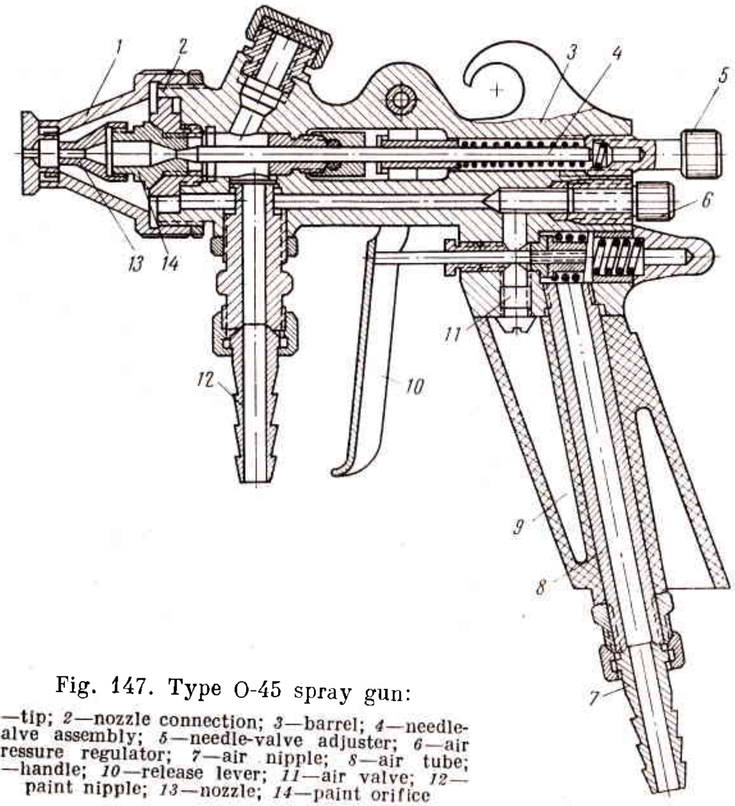


Fig. 147. Type O-45 spray gun:

1—tip; *2*—nozzle connection; *3*—barrel; *4*—needle-valve assembly; *5*—needle-valve adjuster; *6*—air pressure regulator; *7*—air nipple; *8*—air tube; *9*—handle; *10*—release lever; *11*—air valve; *12*—paint nipple; *13*—nozzle; *14*—paint orifice tube *4*, through the cock *5*, the hose *6* and into the spray gun. The stirrer *3* agitates the paint in the bucket.

The Type O-45 spray gun used in the outfit (Fig. 147) has a barrel *3* with two separate passages, one for compressed air entering by a nipple *7*, and the other for paint admitted through another nipple *12*. Pressure on the release lever *10* opens both the paint nozzle *13* and the air valve *11*. The air atomizes the paint and blows it against the surface to be coated. By insertion of an adapter into the gun, the spray of paint can be made flat, elliptical or round.

Where small parts are to be painted or painting done on a limited scale, use is ordinarily made of a spray gun to which a paint dispenser is attached. This eliminates the pressure tank and simplifies the spraying outfit considerably.

The tanks, conservators, covers and other parts of Size 1 and 2 transformers are painted in a painting chamber (Fig. 148). The painted parts are lifted by a floor-operated monorail hoist and moved through a drier where the paint dries at about 80°C in an hour and a half.

Assembled or dismantled Size 3 transformers (i.e., their tanks, conservators, etc.) are painted in a booth (Fig. 149). The booth has ample exhaust ventilation and a sliding roof, so that paint cannot get onto other parts in the area and working conditions are greatly improved. The tubes leading to the exhaust header *3* are fitted with filters *5* which catch the paint which might otherwise clog the exhaust and get into the surrounding air. The filters are cleaned at regular intervals.

The roof of the booth can slid open both ways. It is opened from the control panel just before a transformer or a transformer part is to be loaded into, or unloaded from, the booth, which is done by means of an overhead travelling crane.

The transformer to be painted is lowered onto the turntable *2* in the centre of the booth, driven by an electric motor.

Painting is done from a truck riding a rail track *6*. The truck can move as far as, and on to, the turntable. The workman stands on the vertically extending platform which also carries a push-button station to control the turntable, the truck and the exhaust ventilation.

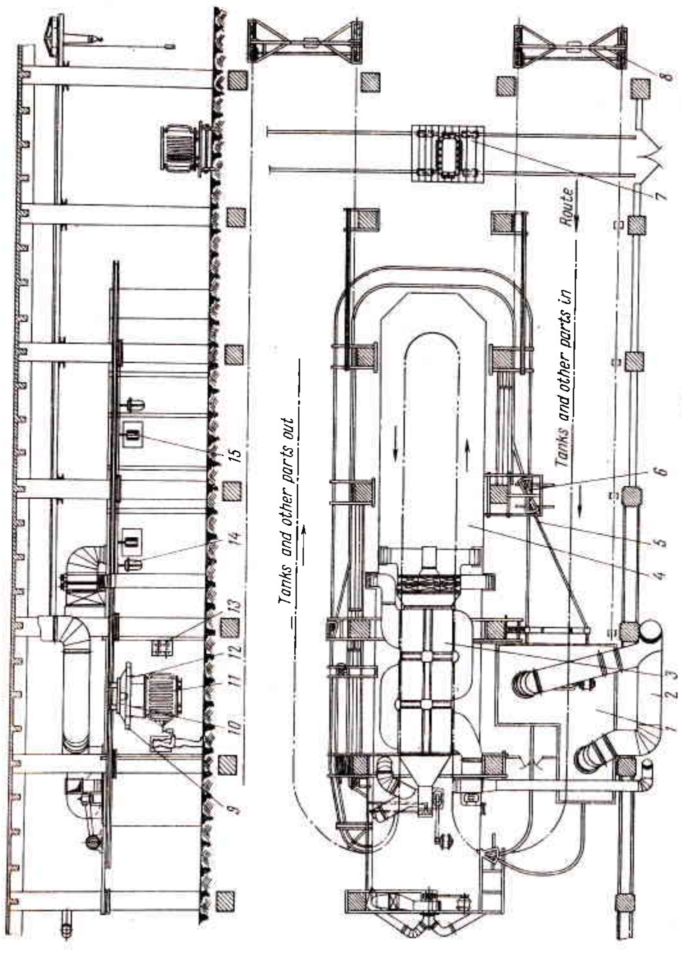


Fig. 148. Painting chamber for tanks and other parts of Size 1 and 2 transformers:

1—painting area; *2*—exhaust ventilation of painting chamber; *3*—air heater of drying oven; *4*—drying oven; *5*—floor-operated monorail hoist to handle transformer parts; *6*—monorail hoist switch; *7*—shunting truck; *8*—gantry crane; *9*—monorail hoist trolley; *10*—girder; *11*—transformer tank; *12*—hook; *13*—wall-mounted sealed lighting fixtures; *14*—sealed lighting fixtures; *15*—sealed oblique lighting fixtures

The truck enters the booth through a gateway *4* with sliding curtains. An interlocking system will automatically stop the motor, if the curtains are not drawn together. Also,

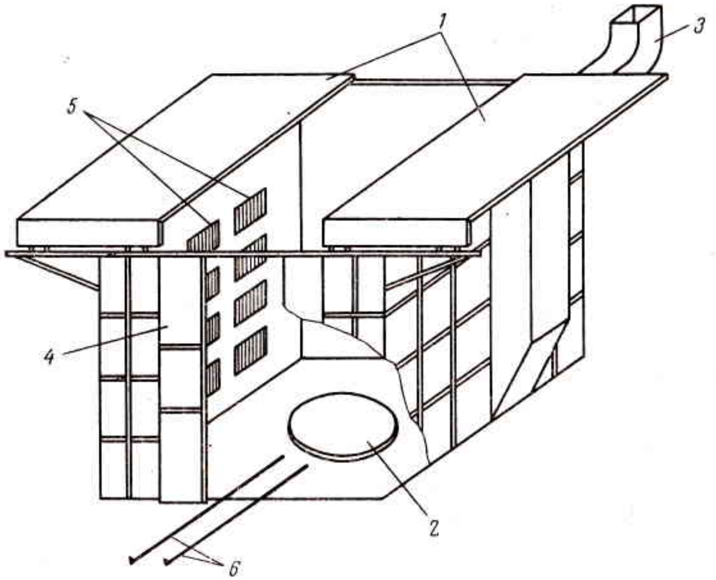


Fig. 149. Booth for painting Size 3 transformer tanks:

1—rolling roof; *2*—turntable; *3*—air outlet pipe; *4*—booth doors; *5*—filters; *6*—rail track

the transformer set up on the turntable can be turned on only if the truck has been fully withdrawn from the booth. All of these features speed up work and add to the convenience and safety of personnel.

The hermetically sealed lighting fixtures built into the roof can be so grouped as to illuminate the transformer side facing the truck in the best possible way.

After the transformer side facing the truck has been painted, the workman backs the truck out of the booth and starts the motor of the turntable to make accessible another side. In this way, he can paint a transformer quickly and well without stepping down from his truck.

For good paintwork to be obtained, it is essential to clean thoroughly the metal surface to be coated. The tanks of Size 1 and 2 transformers are shot-blasted. After mechanical cleaning, the surface is wiped with wastes, examined for possible defects and painted, if none is detected.

The inside surfaces of the tank and cover are painted with Grade 624-C oil-resistant nitrocellulose lacquer, while the outside surfaces are coated with Grade ФСХ-23 enamel after they have been given a coat of No. 138 primer to improve the adherence of the finish coat. The primed surface is allowed to dry in air for 24 hours before the finish coat is applied. If the finish coat were applied to a wet primer, poor paintwork would result.

For some time past there has been a growing trend to use the flow method of paint application. The flow method gives excellent surface coverage and saves much paint.

A simpler method of paint application is dipping which lends itself readily to mechanization. The dipping equipment consists of a large tank, a conveyer and a drying chamber. Transformer radiators are painted by dipping.

As stated earlier, transformers not equipped with conservators have their tanks only partly filled with oil to leave enough space for oil expansion. As a result, moisture might condense on the inside surface of the tank cover exposed to air, and droplets of condensate might get into the oil. To avoid this, the inside surface of the tank cover has to be given a coat of an anti-condensate paint. An anti-condensate paint is usually made on the basis of Grade 624-C lacquer which cannot be used for the purpose alone. The paint is obtained by mixing 84 per cent of well-stirred Grade 624-C lacquer and 16 per cent of well-dried beechwood sawdust. The mixture is applied as a continuous coating to the thoroughly cleaned inside surface of the tank cover. The coat should be 2 to 3 mm thick. A reduction in the coat thickness is intolerable even at isolated spots.

The coated surface is then kept horizontal for at least a half-hour so as to obtain a uniform thickness throughout. Drying is done at 60° to 70°C for two hours. If dried in air at 16°C, the cover may be put on the tank after at least five hours. If Grade 624-C lacquer is not available, the anti-condensate paint may be prepared on the basis of Grade ГФ-95 alkyd varnish, drying it at 60° to 70°C for 18 hours.

72. Preparation of the Tank

The tanks of Size 1 and 2 transformers arriving for the third stage of transformer assembly are set up directly on the floor. The tanks of Size 3 transformers are mounted on stationary trestles set up over an oil-drain grate. The top platform of a trestle is raised to a height convenient and safe to work.

When lifting a Size 3 transformer, the lifting ropes must be hooked on the four lifting lugs welded at the corners of the tank. Lifting by two lugs across a diagonal will partly deform the tank walls, and it will be difficult to lower the core-coil assembly into the tank.

Before the tank of a Size 3 transformer is set up on a trestle, the drain plug in the bottom must be reliably sealed. The plug should be sealed with asbestos cord impregnated with Grade ГФ-95 alkyd varnish and held in air for three or four hours. The impregnated cord should be tightly wrapped around under the plug head. The plug is then screwed into its hole and tightened with a spanner as far as it will go. If this operation is properly done, a reliable seal will be obtained.

After a tank has been set up on a trestle or on the floor, it should be examined in the inside for left objects or dirt. The left objects, if any, should be removed, and the dirty spots should be wiped clean with lint-free wastes.

Next the frame on the top of the tank is wiped clean, and strips of oil-resistant rubber gasket are given a uniform and thin coat of rubber cement with a rush. When the cement dries in 10 to 15 minutes, the rubber strips are placed on the top frame. The rubber should fit snugly to the frame between the holes for the cover bolts and the projecting edge of the tank wall (Fig. 150). Special care must be exercised in placing rubber strips on the rounded corners. Lack of care may result in that the rubber will be squeezed inside the tank when the cover is bolted down onto it.

The joints between rubber strips should be made on the straight portions of the top frame. The joints must be made oil-tight without increasing the thickness of the gasket.

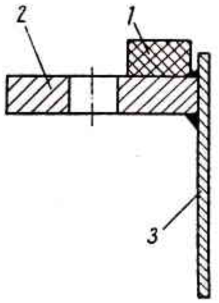


Fig. 150. Tank top frame with a rubber seal installed:

1—seal; 2—top frame; 3—tank wall

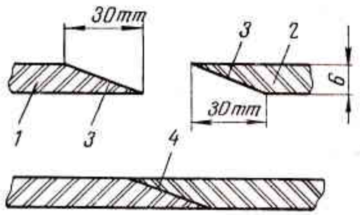


Fig. 151. A method for installing the cover rubber seal:

1 and 2—rubber strips; 3—line of cut; 4—line of cut after joining

Ordinarily, scarfed joints are used as shown in Fig. 151, with the strips scarfed for a distance of 30 mm from the end.

73. Tanking of Size 1 Transformers

Finishing of the Core-coil Assembly. Before the core-coil assembly can be finished and tanked, it should be thoroughly inspected for mechanical injury on the windings, cracks and warpage in the wooden parts, misplaced and improperly connected tappings. Defects, if any, should be immediately remedied.

During the drying of the core-coil assembly, the insulation, wooden and pressboard parts shrink, and the coils and leads become loose. Therefore the first step in the finishing of the core-coil assembly is to take up any slackness in the coils by tightening the nuts on the tie-rods, thereby pulling the wooden coil-end blocks down onto the windings. Next the nuts on the studs of the top and bottom yokes are tightened as far as they will go. Then the bolts of the wooden cleats, the terminal studs and fastening bolts of the tapping switch are tightened, with the contact shoes of the switch set in the middle position.

To prevent them from working loose in service, the nuts, the tie-rods and the bolts of the wooden cleats, tapping switch and other parts on the core-coil assembly are centre-punched at three points round the circumference. The core-coil assembly is then blown with compressed air under a pressure of 2 to 3 atmospheres (gauge) and, just before it is to be lowered into the tank, tested with a 1,000-volt megohmmeter for:

—the insulation level of the tie-rods to the core and yoke clamps;

—the insulation level of the H.V. and L.V. windings to earth and to each other (the insulation resistance should be not lower than 100 megohms);

—open circuits in the windings and the tapping switch (the test should be done on each phase or between phases with the switch set in all possible positions).

In the case of an open circuit in the windings or the tapping switch, the megohmmeter will read infinity.

Tanking. After inspection, the core-coil assembly is lifted by an overhead travelling crane and held suspended to wipe clean the support bars of the core and to centre-punch the nuts on the bolts fastening the support bars at three points round the circumference. Then wooden blocks are placed on the angles welded to the inside of the tank, the core-coil assembly is inspected again and lowered on the wooden blocks. While lowering the core-coil assembly (Fig. 152), care must be taken to keep the wooden and current conducting parts clear of the tank walls, since otherwise the wooden parts or the insulation may be damaged.

If the core-coil assembly hangs on the angles, it should be lifted by crane, the wooden blocks reduced in thickness, and the core-coil assembly lowered again. Make sure that the core-coil assembly is positioned in the tank correctly and that all the clearances from the windings and leads to the tank walls and other earthed parts conform to the drawing. Then the core-coil assembly is reliably locked on the angles by nuts.

The shaft of the tapping switch is positioned by shifting the tapping switch on the core-coil assembly to a template

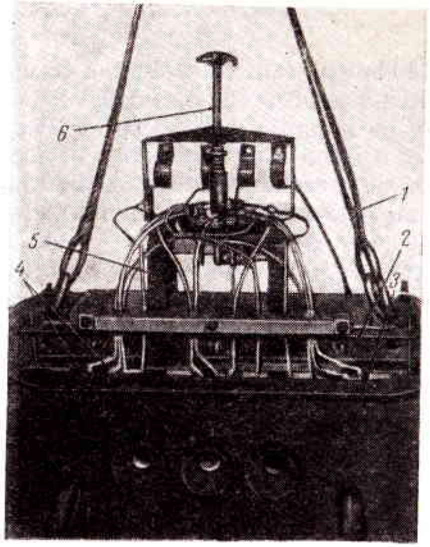


Fig. 152. **Tanking** the core-coil assembly of a Size 1 transformer:
1—lifting slings; *2*—core-coil assembly; *3*—tank; *4*—bushing pockets in tank wall; *5*—tapping switch mounted on core-coil assembly; *6*—tapping-switch shaft

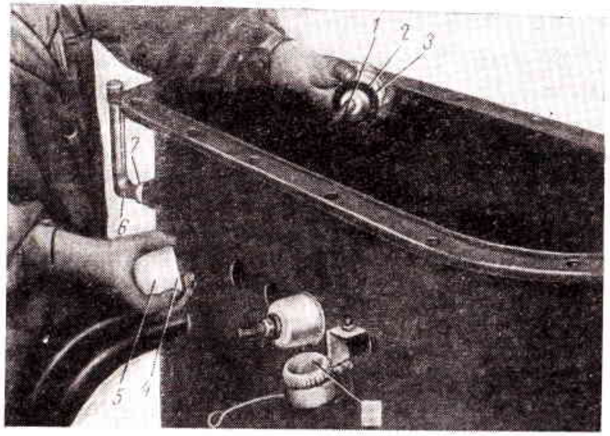


Fig. 153. Mounting a built-up L.V. terminal bushing on a tank wall:
1—terminal; *2*—rubber washer; *3*—bottom shell; *4*—pressboard washer; *5*—top shell; *6*—oil gauge; *7*—oil-gauge elbow-sealing nut; *8*—fuse

which should be placed on the top frame of the tank. After the switch has been fixed, the H.V. and L.V. terminal bushings may be mounted. If the core-coil assembly is not to be attached to the tank cover, use is made of built-up terminal bushings which are set up on the tank wall. Installation of a built-up terminal bushing is shown in Fig. 153.

A built-up bushing consists of a terminal *1* and two porcelain shells, bottom *3* and top *5*. The terminal, with a steel square nut welded to it and a square rubber washer placed under the nut, is inserted into the bottom shell, and another rubber *2* washer is placed on the shoulder of the shell. The bottom shell of the terminal bushing thus assembled is inserted into the hole in the tank wall with the left hand, a pressboard washer *4* is placed on the projecting end of the bottom shell, and the top shell *5* is seated over it with the right hand.

Now two washers, one of pressboard and the other of copper, are placed on the terminal, and a brass nut is then run on with an open-end or a box spanner. The rubber washers make the joints in the terminal bushing oil-tight, while the pressboard washers make up for any surface irregularities on the tank wall or the insulator. The same procedure is followed in the case of all the terminal bushings on a transformer. After the terminal bushings have been installed, the H.V. and L.V. leads are carried to them and tightened with two lock-nuts.

Before mounting built-up terminal bushings, they should be wiped inside and outside with wastes moistened with a solvent.

The position indicator of the tapping switch is fastened on the tank cover with three screws. Then the operating handle is lifted off the shaft of the switch fastened on the yoke clamps and the cover is placed on the top frame of the tank.

Next, bolts are inserted into the holes in the cover and the top frame, nuts are run onto the bolts and tightened uniformly all the way round the perimeter of the tank with an open-end spanner or a Type ЭГ-12 nut-driver. Now the operating handle is replaced on the switch shaft and locked with a stop screw.

The oil gauge *6* (Fig. 153) is screwed into the nipple welded to the tank wall. To obtain an oil-tight joint, the elbow of the oil gauge is wrapped with asbestos cord impregnated with Grade ГФ-95 alkyd varnish and clamped with a nut *7*. The thermo pocket is mounted on the tank cover.

This done, the No. of the transformer is stamped on the H.V. side of the cover and also on the plate welded to the tank on the L.V. side.

The fuse (if any is specified in the drawing) should be mounted on an angle welded to the tank wall.

After visual inspection, the transformer is filled with oil and watched for two hours for any oil leaks at the joints. If there is no oil leakage, the transformer is handed over to the testing station for tests.

74. Tanking of Size 2 and 3 Transformers

General. The tanking procedure in this case differs from the one described above. The cover is first clamped on the lifting rods, the leads are connected up, and then the core-coil unit is lowered into the tank together with the cover. Because of this, the sequence of assembly is somewhat changed. In the case of Size 3 transformers, tanking is done on stationary trestles set up over oil-drain grates, which fact makes work more convenient.

Finishing of the Core-coil Assembly. Special emphasis is placed on the inspection and finishing of the core-coil assembly after drying. First of all, the coil spacers and the spacing blocks on the coil-end and yoke washers are checked for alignment. Then the winding cylinders and the wooden parts bracing the coils and leads are inspected. Defects, if any should be revealed, are remedied at once.

The first step in the finishing of the core-coil assembly is to take up any slackness in the windings by tightening the nuts on the tie-rods. The nuts should be tightened in turn, a little at a time, so that the yoke clamps are not cocked. As a result, the wooden blocks, coil-end collars and yoke washers will be clamped snugly to the windings.

Now the nuts on the studs of the top and bottom yokes are run down as far as they will go. The tie-rods, studs and nuts are centre-punched at three points round the circumference to prevent them from working loose in service.

Before the tank cover can be placed on the tank, the lifting rods should be prepared for the operation (Fig. 154). To do this, the lifting eye *7*, nut *6* and washer *5* are removed from each lifting rod, while leaving the bottom nut *2* and washer *3* in place. The level at which they are left should correspond to the height of the tank with allowances for possible deviations.

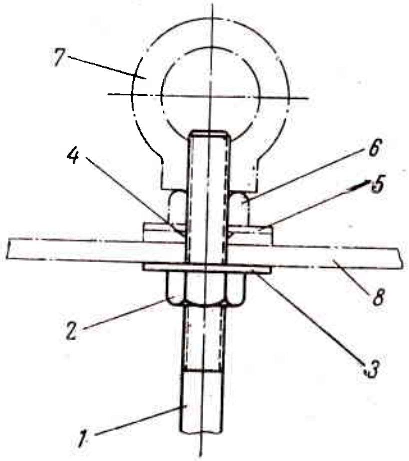


Fig. 154. Accessories of a lifting rod of a transformer:

1—lifting rod; *2*—bottom nut; *3*—bottom washer; *4*—asbestos cord; *5*—top washer; *6*—top nut; *7*—lifting eye; *8*—tank cover

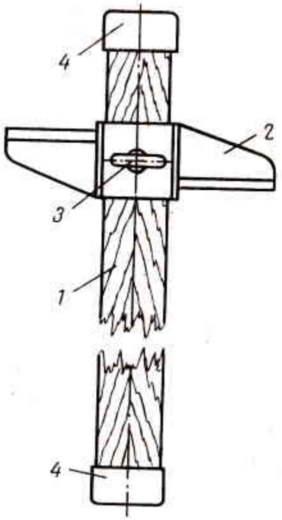


Fig. 155. Batten to measure the depth of a tank:

1—wooden batten; *2*—arm; *3*—set bolt; *4*—steel cap

Since the cover is mounted on the lifting rods which pass through holes in the cover, it is essential to seal these holes properly. This is done with asbestos cord impregnated with Grade ГФ-95 alkyd varnish and kept in air for three to four hours. The asbestos cord is wrapped several times around each rod and above the washer *3*.

The depth of the tank is measured with a wooden batten carrying a movable arm which can be locked in the required position by a set bolt (Fig. 155). To measure the depth of a tank, the batten is lowered as far as the bottom, the arm is set a little above the top frame (five or six millimetres), and the arm is locked in that place with the bolt.

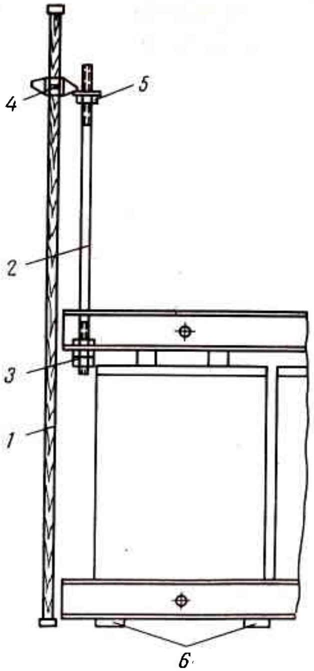


Fig. 156. Mounting the top nuts on lifting rods:

1—batten; *2*—lifting rod; *3* and *5*—nuts; *4*—arm; *6*—support blocks

After the depth of the tank has been found, the lifting rods *2* (Fig. 156) are adjusted for it by means of the nuts *3* on the top yoke clamps so as to obtain this distance between the bottom surface of the support blocks *6* under the bottom yoke clamp to the top surface of the tank cover.

Since, prior to tanking, the weight of the tank cover is carried only by the nuts *5* and washers, the position of the cover is determined by the position of these nuts and washers on the lifting rods.

For the proper location of the cover, the lifting rods should be properly positioned on the top yoke clamps. On the one hand, they should be reliably secured in the yoke clamps, on the other, they should not extend above the cover more than is necessary for the washers, nuts and lifting eyes to be mounted on them. Account must also be taken of the threaded portion at the top ends of the lifting rods: it should be long enough for the nuts left on them to be run up or down, as the case may be.

Installation and Fitting Out of the Cover. The cover is lifted by crane, using the fixture of Fig. 157, and is taken to the core-coil assembly. Then it is gradually lowered, steering it so that the lifting rods fit into the holes in the cover. Then washers are placed, and the nuts and lifting eyes are screwed onto the rods.

Now the rods are reliably coupled to the cover and finally locked in position on the top yoke clamps (Fig. 156). To do this, the nuts on the bottom ends of the rods are tightened as far as they will go and centre-punched to prevent them from working loose in service.

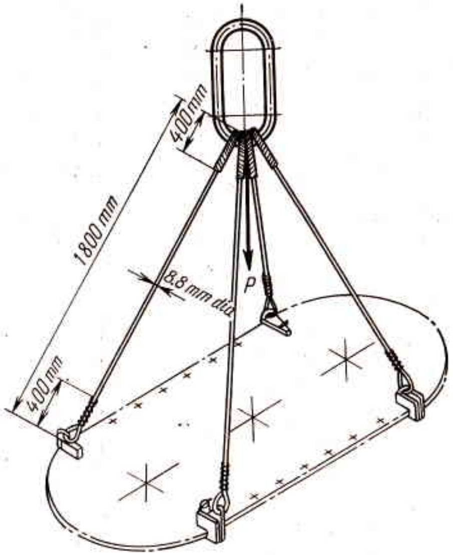


Fig. 157. Fixture for lifting the cover

Some of the Size 2 transformers have lifting rods fastened to angles which are in turn bolted to the top yoke clamps. In such a case, the nuts should be also tightened as far as they will go and fitted with lock-washers.

Next the cover is fitted out with all the accessories: the H.V. and L.V. terminal bushings, the tapping switch, the cock, the thermo pocket and others. On Size 2 transformers, the conservator and the relief stack are mounted after the core-coil assembly has been tanked.

Both the tank and the cover should be oil-tight. Therefore special emphasis in fitting out should be placed on the joints between the accessories and the cover. The joints

are sealed with oil-resistant rubber gaskets placed between the tank cover and the accessories.

Round holes should be sealed with ready-made rubber rings. If such are not available, they may be cut from sheet rubber in which case too much rubber will be wasted.

The flanges of the terminal bushings, the cover of the tapping switch, the cock and the thermo pocket should also be sealed with ready-made gaskets of oil-resistant rubber. Prior to installation, their locations should be thoroughly wiped with wastes. The H.V. and L.V. terminal bushings should be selected in accordance with the overall dimensions of the transformer. The outline drawing always specifies the distance from a terminal bushing to the cover, the number of watersheds on outdoor bushings and also the dimensions of the terminal or spade lug on the H.V. bushings. Therefore, prior to installation, the terminal bushings should be checked for size against the outline drawing of the transformer.

The more recent trend has been towards using detachable terminal bushings. Detachable bushings are easier to replace in the case of failure, which can be done without lifting the core-coil assembly out of the tank.

Detachable bushings can be mounted on the cover both before and after the tanking operation. Prior to installation, the H.V. and L.V. bushings, examined and checked for dimensions, are rubbed with clean lint-free wastes moistened with a solvent and then wiped with dry wastes. This seemingly minor operation is very essential, because in the measurement of the insulation resistance of the L.V. and H.V. windings in Size 3 transformers a dirty terminal bushing will appreciably increase the conductance over the surface of the insulator. Sometimes, this may result in a flash-over when the insulation is being tested with an applied voltage.

With the porcelain shells thoroughly washed, the terminal bushings are mounted exactly as shown in the drawing. The nuts on the studs should be tightened gradually and uniformly all the way round the circle so that the cover is not cocked or the gaskets dislodged.

After the terminal bushings have been set up on the cover, the tapping switch, cock and thermo pocket are mounted. In all cases the nuts should be tightened uniformly all the way round the circle. The terminal studs of the tapping switch should be tightened before installation on the cover.

Preparation of the Core-coil Assembly for Tanking. It is extremely important to connect the tappings from the H.V. winding to the switch and the L.V. and H.V. leads to the terminal bushings neatly and correctly, maintaining the spacings and clearances specified in the drawing. Each nut screwed onto a bolt should be tightened as far as it will go with a spanner and locked with a lock-nut for reliable fixation. The core-coil assembly is then blown with compressed air under a pressure of 2 to 3 atmospheres (gauge), and the terminal bushings are again wiped with dry wastes.

The final step in the preparation of the core-coil assembly for tanking is to test the insulation level, including that of the tappings and leads. First, using a megohmmeter for at least 1,000 volts, the earthing is tested and also the insulation of the bolts on the top and bottom yokes to the core and yoke clamps, then the insulation level of the H.V. and L.V. windings to each other and to earth.

The insulation resistance should be not less than 100 megohms. If a reduced reading is obtained, the cause must be detected and remedied. The low insulation resistance of a terminal bushing is an indication of dirt on its surface; after it has been washed and wiped dry, the insulation resistance usually increases.

The low insulation resistance of a yoke bolt may be due to a short synthetic-resin-bonded paper tube, a damaged pressboard washer or accidental dirt.

The cause of the reduced insulation resistance of the windings and bushings is more difficult to ascertain. Most often the reduction is due to excessive moisture as a result of a long stay of the core-coil assembly in the air or because of improper drying; the damaged pressboard cylinder of the L.V. winding in Size 1 and 2 transformers; or a defective porcelain shell in one of the terminal bushings.

In order to determine the cause of the reduced insulation resistance of the windings, the leads should be disconnected from the respective terminal bushings, and their insulation level to earth checked.

For the identification of the phase responsible for the reduced insulation resistance, the star-connected phases of the L.V. winding should be separated and checked separately. Defects, if any, should be remedied, and the insulation resistance measured again with a megohmmeter.

The tapping switch is tested for contact, and the H.V. winding for open circuits also with a megohmmeter. The test should be done either on each phase or between phases in every position of the switch. In the case of an open circuit in the H.V. winding or the switch, the megohmmeter will read infinity.

Tanking. The core-coil assembly is lifted a short distance above the floor or the trestle with the crane slings attached to the lifting eyes screwed onto the top ends of the lifting rods. With the core-coil assembly held suspended, the support blocks thoroughly wiped clean, the nuts on the bolts fastening the blocks are tightened and centre-punched at three points to prevent them from working loose.

After another inspection, the core-coil assembly is lowered into the tank, exercising utmost care and following the instructions of the outline drawing. Sometimes it will suffice to push the core-coil assembly a little aside, and it will fit into the tank easily. When tanking, the core-coil assembly should be steered with two steel round bars about 300 mm long, inserted into the holes in the cover and the top frame of the tank.

The correct positioning of the core-coil assembly in the tank is important from the view-point of both transformer performance and transportation by rail. After the core-coil assembly has been lowered into the tank, its height is adjusted by tightening the top nuts *6* on the lifting rods a little (see Fig. 154). Then the core-coil assembly is lifted 400 to 500 mm above the top frame of the tank, the top nuts are backed off one turn, and the bottom nuts *2* under the cover are tightened as far as they will go. Then the nuts are centre-punched at three points round the circumference.

Now the core-coil assembly, with the cover put in place, is carefully lowered into the tank. When the cover is within

100 to 150 mm of the top frame of the tank, two tapered steel bars 300 mm long are inserted into the bolt holes on the opposite sides of the cover, and the assembly is manoeuvred so as to "register" with the corresponding holes in the top frame. With the bolt holes in the cover and the top frame thus lined up, the assembly is lowered all the way down. Usually, the holes in the cover and the top frame line up. They will not line up only if the tank has been distorted because the lifting slings were improperly attached in handling.

Now bolts are inserted into the holes. Where the holes are not in registry, tapered steel bars should be driven into them with a sledge-hammer as far as they will go so as to align the cover and the top frame and to make it possible for bolts to enter the holes.

Next, nuts are run onto the bolts inserted into the respective holes. The nuts should be tightened either with a Type ЭГ-12 nut-driver (Fig. 158) or with a spanner having an increased leverage, going over from side to side of the cover and tightening the nuts uniformly.

All the joints in the cover and the top frame of the tank should be reliably sealed. After the core-coil assembly has been tanked, the lifting eyes and nuts should be removed from the lifting rods, and asbestos cord impregnated with Grade ГФ-95 alkyd varnish should be looped several times around the lifting rods under the washers. After the asbestos cord has been wrapped around the rods, the washers are replaced, and the nuts are run down onto the rods to apply sufficient pressure to the asbestos packing. Then an earthing conductor is put on one of the lifting rods and fastened with a bolt to the cover or top frame of the tank. The lifting rods are now fitted with lifting eyes again.

The next step is to mount the brackets for the conservator on the cover. Then the conservator is set up on the brackets and fastened to them with bolts and nuts after a rubber gasket has been placed under the flange of the pipe connecting the connector and the main tank. On Size 3 transformers, the conservator and the relief stack are usually mounted on the cover in the welding shop.

After the conservator has been fastened in place, the oil gauge is mounted. The elbow of the oil gauge is screwed

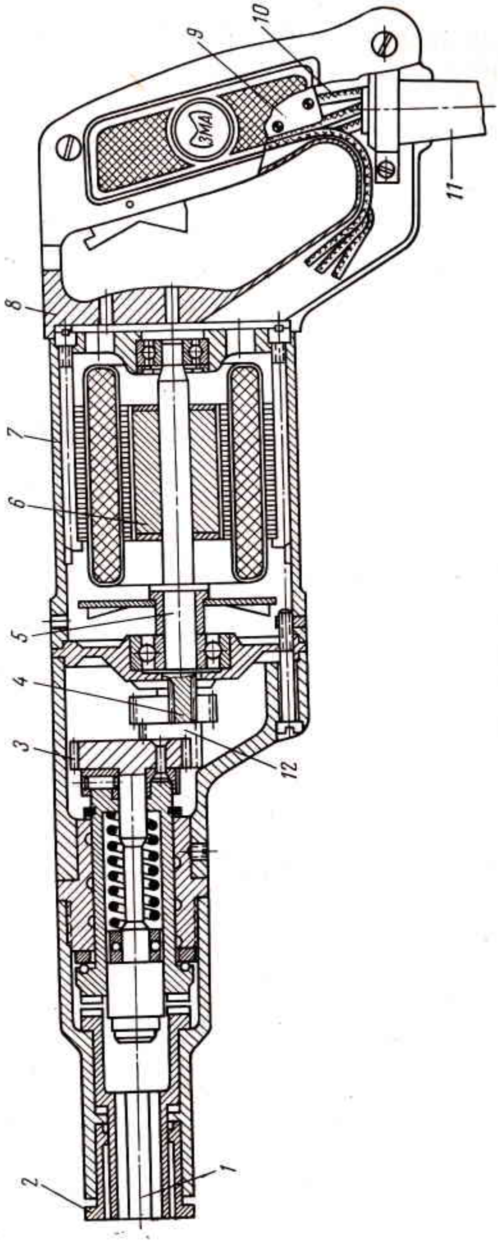


Fig. 158. Nut-driver:

1—arbor; *2*—bushing; *3*—reduction gear; *4*—bevel gear; *5*—spindle; *6*—rotor; *7*—aluminium body; *8*—handle; *9*—switch; *10*—cable; *11*—rubber cap; *12*—reduction gear unit into the nipple welded into the side wall of the conservator. To make the joint oil-tight, asbestos cord impregnated with Grade ГФ-95 alkyd varnish is wrapped several times around the elbow, and a special nut is run on.

Next the serial number of the transformer is stamped on the cover on the H.V. side near phase *A* and also on the nameplate welded to the tank.

After visual inspection, the assembled transformer is filled with oil. Before that, the cock (if there is any) and the top plug on the conservator should be opened. Oil is poured through the bottom cock. As the tank is filled, the oil displaces the air from the tank through an opening in the conservator.

When filling with oil, the oil gauge should be watched, since there is no other means to indicate oil level in the tank. Filling should be stopped when the conservator is filled half-full. All joints and connections should be thoroughly wiped with wastes.

The oil-tightness of welded and other joints is checked by visual inspection after 2 hours in the case of Size 1 and 2 transformers, and after 12 hours in the case of Size 3 transformers. If no leaks are detected, the transformer may be handed over to the testing station for final tests.

75. Tanking in the Case of the Type ATMK-100/0.5 Moving-coil Voltage Regulator

Tanking in the case of the moving-coil voltage regulator differs from the operation described in the previous section. Since each phase of the regulator is dried separately, the assembled core-coil unit mounted in the operating-mechanism frame needs no additional drying.

Testing of the Core-coil Assembly. Prior to tanking, the core-coil assembly of the moving-coil voltage regulator is tested at the testing station for:

— the d.c. (ohmic) resistance of the windings (for each phase separately);

— the insulation resistance of the windings and the bolts fastening the coil frames;

— the electric strength of the insulation of the windings and the operating-mechanism circuits;

— the inter-turn insulation of the windings by means of an induced voltage during a trial run of the operating mechanism;

— the transformation ratio and the asymmetry of the secondary voltages with the short-circuited coils positioned at the top, middle and bottom of the fixed coils;

— no-load loss with the short-circuited coils at the top, middle and bottom of the fixed coils.

Also, the operating mechanism is given a trial run during 10 to 15 minutes with the case earthed. The operating mechanism should work smoothly, without seizure, stops or heavy noise. The motor and bearings should not grow hot.

During the test, the moving short-circuited coils are evened up with respect to the fixed coils. These operations cannot be fully carried out on a fully assembled regulator. Also, it is extremely difficult to remedy the defects of assembly, if there should be any.

Tanking. After the tests, the core-coil unit comes for the third stage of transformer assembly. Before going any further, it is inspected for mechanical injury to the windings, leads, wooden parts and operating mechanism.

Then all the bolted connections are examined and loose nuts are tightened. If the phase assemblies are not properly fastened, the leads may be broken and the short-circuited coils may be displaced in their frames in handling. Also the top and bottom yokes are examined for slackness. If necessary, the slackness is taken up by tightening the yoke bolts, and their nuts are again centre-punched to prevent them from working loose in service.

Then the bolts fastening the frames of the moving coils are tightened and locked with another nut. This should be done with care so as not to damage the insulation of the frame bolts. Should the insulation be damaged, a short-circuited turn will be formed, causing local heating of the winding wire, because of which the regulator may fail completely.

The bolts fastening the leads should be tightened as far as they will go. Good contact between the leads and the terminal bushings can be obtained by tightening the nuts on the terminals. The clearances should conform to the drawing.

The terminal bushings should be wiped with clean wastes moistened with a solvent. Finally, the core-coil assembly is blown with compressed air under a pressure of 2 to 3 atmospheres (gauge).

Then the core-coil assembly is again inspected and tested with a megohmmeter for at least 1,000 volts for:

— the insulation resistance of the fixed coils to earth (it should be not less than 100 megohms);

— the insulation resistance of the top and bottom yoke bolts to the core and the yoke clamps (the angle irons);

— open circuits in the windings;

— the insulation level between the clips of the frames carrying the moving coils;

— earthing of the core.

After the core-coil assembly has been inspected and tested as outlined above, a three-sling tackle *4* (Fig. 159) is hooked on the three lifting eyes *3* on the top plate of the operating mechanism, and the core-coil assembly *2* is lifted about 1.5 metres by an overhead travelling crane. While the assembly is held suspended, the tie-rods of the bottom plate are examined for fixation, the bolts are tightened and centre-punched, and the bottom plate is wiped clean with wastes.

Before the core-coil assembly is tanked, the outline drawing should be consulted in order to determine on which side of the tank the terminal bushings are to be located. In tanking, utmost care should be taken not to damage the assembly. In tanking, the core-coil assembly should be guided by two round steel bars about 300 mm long, inserted into the holes in the top frame and cover of the tank. Using these bars, the core-coil assembly is steered so as to line up the holes in the cover and the top frame. Then bolts are inserted into the holes.

Next, nuts are run onto the bolts and tightened either with a nut-driver or with a spanner having an increased leverage. The nuts should be tightened uniformly, going from side to side of the cover and from nut to nut in equal steps. If the top plate of the operating mechanism is cocked (even insignificantly), it will not be rotated by hand.

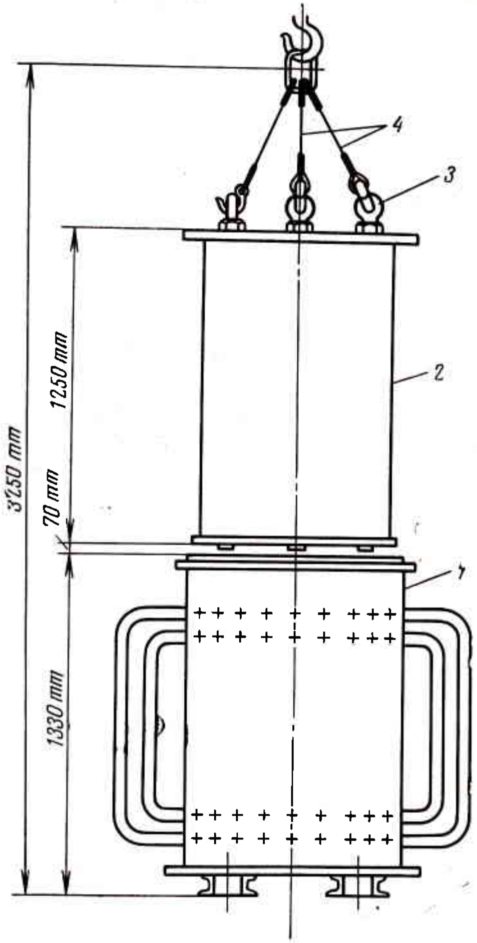


Fig. 159. Tanking of a moving-coil voltage regulator:
1—tank; *2*—core-coil assembly; *3*—lifting eye; *4*—three-sling tackle

Then the cover (the top plate of the operating mechanism) is fitted with a thermo pocket mounted on a rubber gasket, and the nuts of the pocket are tightened uniformly.

The oil gauge *2* (Fig. 160) is screwed into the threaded boss *5* welded into the tank wall *6*. The threaded connection is sealed with asbestos cord impregnated with Grade ГФ-95 alkyd varnish and wrapped several times around the elbow *3* of the oil gauge. The asbestos packing is clamped by a nut *4*.

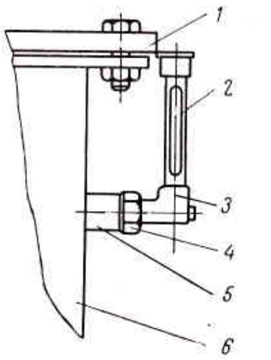


Fig. 160. Mounting the oil gauge on a moving-coil voltage regulator:

1—tank cover; *2*—oil gauge; *3*—oil gauge elbow; *4*—clamp nut; *5*—threaded boss; *6*—tank wall

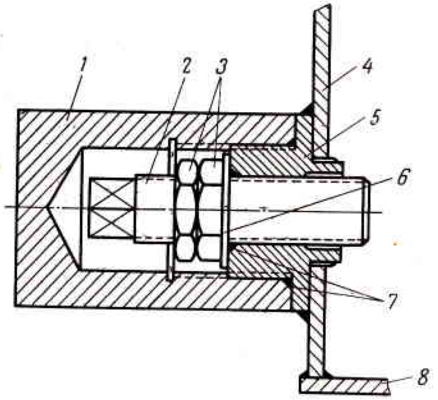


Fig. 161. Mounting of the core-coil assembly in the tank of a moving-coil voltage regulator:

1—cap nut; *2*—stop bolt; *3*—nuts; *4*—tank wall; *5*—steel bushing; *6*—washer; *7*—asbestos cord; *8*—tank bottom

The serial number of the transformer is stamped on the cover and a wall of the tank.

Special attention should be paid to the fixation of the core-coil assembly in the tank. It is important to lock the assembly in as to prevent any displacement of the operating mechanism with respect to the tank walls.

The location of the core-coil assembly in the tank is secured with three stop bolts *2* (Fig. 161) in the lower portion of the tank. After the core-coil assembly has been tanked, the bolts are screwed into the wall *4* so that they bear upon the side of the bottom plate of the operating mechanism. To make the threaded connections oil-tight, asbestos cord *7* impregnated with Grade ГФ-95 alkyd varnish is wrapped several times around the external ends of the bolts and clamped with a washer *6* and nut *3*. To prevent the bolts from working loose in service, another nut *3* is screwed on top of the first nut. For better oil-tightness, the external ends of the bolts are fitted with cap nuts *1*.

After visual inspection, the assembled regulator is filled with oil through the bottom cock until the oil level is at the middle of the oil gauge.

The welded and other joints are checked for tightness by visual inspection after two hours.

76. Final Testing of Transformers

Before it leaves the factory, every transformer, irrespective of its capacity, is subjected to final tests to USSR State Standard 401-41 or to the manufacturer's specifications.

ГОСТ 401-41 and ГОСТ 3484-55 specify the following tests (in the order given):

— the electric strength of the oil;
— the insulation resistance of the windings;
— the transformation ratio;
— the winding connections;
— the electric strength of the insulation with an applied voltage;
— the short-circuit (impedance) test;
— the electric strength of the insulation with an induced voltage;
— the no-load test;
— the d.c. (ohmic) resistance of the windings;
— the loss-angle measurement on Size 3 transformers.

In the case of moving-coil voltage regulator, all the tests carried out prior to tanking are repeated.

Final testing reveals any defects that may be passed unnoticed during the manufacture. An increased d.c. resistance indicates that there is poor contact at the soldered or brazed joints between the tappings and leads and in the tapping switch. Any deviation from the design transformation ratio or from the design winding connections will also be revealed. Increased no-load loss and exciting current will occur if the top yoke has been improperly interleaved or there are several laminations missing in it.

The insufficient thickness of the insulation, reduced clearances between current-carrying and earthed parts, improper drying, dirt on the core-coil assembly, and the poor quality of oil will result in the puncture of the transformer insulation during the tests.

Any defects revealed in a transformer will necessitate partial or complete disassembly of the transformer, involving the waste of money and time.

Each tested transformer is covered by an acceptance-test record and a certificate.

77. *Dismantling for Despatch*

Size 1 through 3 transformers are delivered to electric stations or substations by rail. Therefore, the dimensions of a transformer should conform to the railway loading gauge.

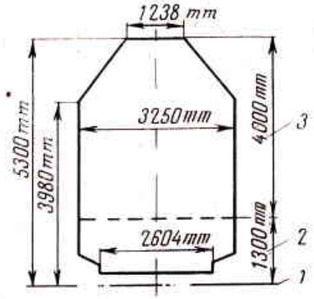


Fig. 162. Loading gauge for Soviet railways:

1—rail head level; *2*—normal height of flat-car platform; *3*—maximum overall height of a transformer on an ordinary flat-car

Size 3 transformers, when fully assembled, exceed the railway loading gauge (Fig. 162), which fact necessitates their partial disassembly. The parts that have to be dismantled are the relief stack, conservator, connecting pipework and mounting brackets. Also, the fittings and accessories which are not essential to the testing of a transformer (such as the tubular radiators, truck, Buchholz relay, thermometer, etc.) are not mounted at the works. They are packed and shipped separately.

The parts dismantled from a transformer are prepared, assembled and shipped together with spares.

As a check on the dismantled parts, they are entered in a special list which is attached to the other papers issued with each transformer. The dismantled-components list is the main guide for the foreman in charge of the dismantling operation.

After the final tests, the transformer to be dismantled for shipping is put on an oil-drain grate where the welded and other joints and all the components that come in contact with oil are again checked for oil-tightness. Should an oil leak be detected during the inspection, the leaky places should be chalked, and the cause should be detected and remedied after a given component has been removed from the transformer.

Concurrently with the check for oil-tightness, the components to be removed are prepared for dismantling. The components to be removed are identified by reference to the dismantled-components list and the outline drawing of the transformer. For convenience in the packing of the dismantled components, tags should be made from pressboard on which the number of the transformer should be stenciled. A hole should be punched in each tag, and the tags should be put on the parts being removed.

The oil from the transformer should be drained to within 70-80 mm of the cover. The relief stack, conservator, connecting pipework and mounting brackets are removed from the transformer by crane. To dismantle the relief stack, it should be secured by a sling to the crane, the flange unbolted, and the rod supporting the relief stack detached.

To remove the conservator, the nuts are unscrewed from the bolts fastening the pipework and the mounting brackets. The conservator is secured to lifting slings, lifted off by crane and placed on an oil-drain grate at a height convenient for work. On the grate, the remaining oil is drained off, the oil gauge is dismantled, and its hole is closed with a tightly fitting wooden plug. The oil gauge is sent to the store room where it is kept until despatch, and a blanking plate is fitted over the hole of the conservator flange.

Any component removed from the cover leaves a hole through which metal objects, such as nuts or bolts always to be found on the cover during disassembly, may get into the tank. To avoid this, any hole in the cover should be immediately closed with a blanking plate secured temporarily with two or three nuts. At the earliest possible convenience, the blanking plates should be reliably bolted in place so as to keep the transformer air-tight.

The following inscriptions should be stenciled on the tank: "Do Not Open Cock Before Blanking Plates Are Removed" and "When Filling with Oil, Unscrew Top Plugs to Let Out Air from Radiators".

After dismantling, the transformer is given final finishing.

78. Final Finishing

After the final tests, when the testing station has supplied the test records, the transformer is given final finishing which consists in the following:

1. The electrical characteristics as determined by the testing station and the weight of the transformer are stamped on the nameplate, and the nameplate is attached to the plate welded to the tank on the L.V. side.

2. Letter designations of the H.V. and L.V. terminals are secured on the cover or wall of the tank.

3. Two tinned washers are put on the tinned earthing bolt which is then screwed into the steel plate welded to the tank wall. The tapping switch is set in the middle position, the stop bolts are tightened on the cover of the tapping switch, and the sign reading "Caution: For Using Switch Refer to Instructions" is rivetted to the switch hood.

4. A fuse is mounted (if specified in the order) on the cover or wall of the transformer tank, depending on the arrangement of the terminals.

5. Oil-level marks are stenciled for different temperatures on the conservator wall where the oil gauge is located. In the case of low-capacity transformers (not fitted with a conservator), oil-level marks are drawn on an angle which is then bolted to the top tank frame behind the oil gauge. A protective jacket is put on the operating mechanism in the case of a moving-coil voltage regulator.

6. The inscription "Lifting Lug" is stenciled on the tank near each lifting lug.

7. The paintwork where it is damaged (on the edges of the tank cover, bolts, etc.) is touched up with ФСХ-23 lacquer. The current-carrying parts of the transformer are given a coating of petrolatum. The top of the thermo pocket is closed with a wooden plug.

8. Seals are applied to the oil-drain plug, the oil-sampling plug and the oil-drain cock after a plug has been inserted.

In the case of Size 3 transformers, final finishing is carried out after the components which may be damaged in transit have been removed.

After final finishing, transformers are examined by a quality inspector.

Chapter

9 Labour Protection and Accident Prevention

79. Labour Protection in the Soviet Union

Labour protection in the Soviet Union is ensured by a system of measures which serve to maintain the health and safety of workers.

As a result of mechanization (especially of labour-consuming, arduous and unhealthy jobs), a number of harmful or dangerous occupations have been eliminated in the USSR and radical improvement has been achieved in the working conditions. All this is done within the framework of the Labour Protection Code and legislative measures of the government.

The maximum working hours in the Soviet Union are seven per day (or six per day for some of the trades). Overtime is not generally practised and may be allowed in exceptional cases only by permission of the factory trade union. Each worker is entitled to an annual paid leave of 12 days during the first two years and additional three days after two years. In some occupations hazardous to health an additional paid leave of 6 to 12 days is given. Persons under 18 are entitled to a month's paid leave.

While on leave, workers can stay at sanatoriums, rest homes and recreation centres. The persons to be employed in hazardous trades are given a medical check-up at the time of engagement and are examined repeatedly at regular intervals.

Child labour in the Soviet Union is prohibited. Persons under 18 work four to six hours a day and are never allowed to work over-time or at night. Every year the trade

union and management of each factory sign an agreement (in addition to collective bargaining) on measures for labour protection, accident prevention and factory hygiene.

80. Accident Prevention

The objective of accident prevention (or safety engineering) is to identify and eliminate causes of industrial accidents. The basis of activity is the study of the industrial processes and operations involved.

In the Soviet Union, every factory has a safety-engineering room where workingmen are instructed in safety methods. Such a room is equipped with broad-sheets and displays on every operation and job, showing correct and incorrect work movements, good and bad tools.

Every workman taking up a job at a factory is given a course of instruction in safety methods in the safety-engineering room. Also there are colour broad-sheets on accident prevention posted near the work stations and on boards about the shop. Every newcomer is given repeated instruction directly on the job. There are special safety instructions for transformer assemblers based on a standard safety code.

When walking about in the factory (outside the transformer assembly department), every workman should be careful and follow pertinent regulations in view of the heavy traffic of electric locomotives, motor vehicles and electric trucks.

81. Safety in the Assembly Shop

A transformer assembly shop or department consists of several independent areas where all the various operations involved in transformer assembly are performed: unblading and reblading of the top yoke, assembly of the L.V. and H.V. windings on the core, clamping of the windings, assembly and joining of the leads, fitting out of the tank cover, and tanking.

Many of these operations are performed by means of an overhead travelling crane, working from ladders. Therefore, the workman should follow all the rules of accident prevention.

Before getting down to work, he should receive additional instructions from his superior (since not all of the features of the work in hand can be covered in written instructions), examine his tools and fixtures (and replace defective ones).

The components to be assembled should be laid out so as to have free access to them. The work station should be free from irrelevant objects. Use may be made only of portable lamps operating on 12 volts, because lamps for 120 or 220 volts are dangerous.

On no occasion should workmen stand or work under the transformer being carried by an overhead travelling crane. As soon as the crane operator gives a warning signal, they should move to a safe place.

Drilling machines, universal shear-punch-bar cutters, copper-bar cutters and other equipment may be operated only by authorized and trained personnel. Prior to work on them, the machines should be checked for missing guarding devices. Any components may be drilled only if they are clamped in machine or hand vises.

When grinding a tool or cutting copper or aluminium on a milling machine or a circular saw, the workman should wear safety goggles. Women, if any are employed in transformer assembly, should wear kerchiefs, since otherwise the hair may get caught by the rotating parts of a machine.

The core-coil unit should be assembled either on a bench or a rack of a size corresponding to that of the transformer and fitted with barriers.

The top yoke should be unbladed not more than 12 to 15 plates at a time. As a protection against cuts, the workman should wear mittens.

Gas torches used to burn off the insulation on conductors should be adjusted for a small flame. Not more than five or six conductors in parallel may be burned off at a time. It should be remembered that the insulation may ignite. After work, the torch should be immediately put out and the gas line shut off.

Utmost care should be exercised in soldering or brazing the connections during the second stage of transformer assembly. Brazing transformers should be energized only after their earthing has been checked and only with a current necessary for brazing (as given in the instructions). Brazing tongs should be in a good state of repair and ensuring good contact. Leads should be welded with safety goggles on. Electric tools (nut-drivers, drills, etc.) should be reliably earthed.

When tanking, care must be taken not to leave any tools on the core-coil assembly or the tank cover. The tools not in use should be returned to their portable boxes or the rack, so that they will not fall (there may be people working under the rack).

Hoses should be connected to and disconnected from the air mains only with the shut-off valve closed. If not properly connected, hoses may come off the nipples, and the issuing compressed air may injure both the workman and persons nearby. After work, the valve of the air mains should be closed and the hoses coiled.

Lifting gear (where transformer assemblers are allowed to use such) should be handled with care. Before lifting a weight, the slings should be examined for any damage and lifting capacity. Any lifting fixtures may be used only for their designated purpose: for lifting the windings, for lifting the cover, for lifting the core-coil assembly, etc.

Workmen in the third stage of transformer assembly should take a shower daily. Hand washing with petrol or acetone must be discouraged, since the skin becomes susceptible to diseases.

Smoking in the transformer assembly shop may be allowed only in a specially reserved area.

Every workman in the assembly shop should know how to use a fire extinguisher and what to do in the case of a fire.

82. First Aid

When properly observed, safety rules prevent accidents. Yet, for some reason or other, accidents do occur. To cope with them, every factory has a well-equipped medical service working on the round-the-clock basis and staffed by experienced physicians. In the case of certain injuries, however, it is important to render first aid to a victim immediately, without waiting for a doctor to arrive, since even a minute's delay may prove fatal.

This is the reason why every man in the assembly shop should be well-versed in the basic rules of first aid, although a physician must be called in all the same.

Medical attendance is a "must" in the case of a severe wound, injury or electric shock. In the latter case, the first thing to do is to free the victim from contact with current. If the victim is unconscious, but breathing is normal and the heart has not stopped, it will suffice to facilitate breathing (by unbuttoning the collar, unbuckling the belt, etc.) and to allow fresh air to reach him (by opening the door, window, sash, etc.). It will be a good thing to put a cotton wad soaked in ammonia water to his nose. As soon as the victim has come to, he should be taken to the medical department on stretchers.

If the victim has ceased breathing or is breathing spasmodically and the heartbeat is uneven, apply artificial respiration at once.

Index

A

Accident prevention, 275
Active power, 20
Alloy steels for transformer cores, 25
Aluminium, 113-15
Aluminium leads, welding, 89
Apparent power, 25
Argon-shielded welding, 192-95
Assembly operations, 127
    first stage, 127
    second stage, 127, 174
    third stage, 127, 243
Assembly tools, 129-34
Autotransformer, 43-46
Auxiliary materials, 124-26
Axial forces, 35, 39
Axial shrinkage, 72
Axial stresses, 74

B

Back-e.m.f., 14
Bar cutter, 196
Beechwood, 118
Bench vise, 129-30
Bender, hand-operated, 201
Bending machine, 198
Bolted joints on leads, 89
Bonded joints, testing, 190
Bonding, 187-91
    bench-tool, 187
Brass, 115
Brazing, electric, 178
    safety in, 276-77
Brazing machine, air-operated, 184
    portable, 178
    stationary, 182
Brazing press, 182
Breather, 104
Buchholz relay, 105, 107
Built-up boards, 121
Bursting force, 34
Bushings, 65
Butt joints, 68-9

C

Cable paper, 117-18
Cable shears, hand-operated, 219
Calipers, 132-34
C-cramps, 130
Circulating current, 55, 58
Clearances, 143
Coil-end insulation, 79, 139, 142, 146-47
Coil-lifting fixture, 152
Coils, 64
    assembly on core, 152
    axial dimensions, 149, 157

  preparation for assembly, 151
  testing for open-circuit, 149-51
  testing for short-circuit, 149-51
Cold chisels, 130
Cold pressure welding, 187-91
Colophony, 125
Complementary losses, 29
Compulsory tests, 173
Concentric windings, 30
Conductor materials, 110-15
Conservator, 262
Continuous-disk winding, 77
Cooling system, 60-62
Copper, 111-13
Copper leads, brazing, 89
Core, 64
  elimination of dents and nicks, 138
  materials, 122-24
  preparation for assembly, 138
  types, 67
Core-coil assembly, 64
  clamping-up, 160-66
  drying, 231-35
  finishing, 251, 255
  preliminary tests, 173
Counter-e.m.f., 14
Cover, installation and fitting out, 257
Crepe paper, 118
Crimping, 184
Crimping tool, 184-86

D

Dehydrator, 104
Delta connection, symbol, 47
Designation, transformer windings, 46-7
Dismantling for despatch, 270-72
Double-layer winding, 74
Ducts, 75

E

Earthing, 73
  arrangements, 73
  connection, 161, 166
  electric tools, 277
Eddy currents, 14, 16, 19
  loss, 16
  reduction, 16, 24
Efficiency, transformer, 32
Electrical materials, 110
Electrical-sheet steel, 122-24
Elliptical cooling tubes, 99
E.m.f., effective value, 17
  self-induction, 20
Enamel, 120
  decorative, 126
End rings, 72, 149
Exciting current, 14, 17
Expansion bends, 212
Expansion tank, 67
Explosion stack, 108
Explosion vent, 67

F

Files, 130
Filling strips, 148-49
Final testing, 269-70
Finishing operations, 243
Flexible connectors, 89, 203, 205-06
Force of repulsion, 35

G

Gas formation relay, 67, 105, 107
Gas torches, stripping, 276

H

Hack-saw, 131
Hammers, 130
Hand vise, 130
Heat dissipation in core, 16
Heat loss, 12, 24, 58
  in primary, 20
  reduction, 12
Heat transfer in transformer, 60
Hole marker, 206
Hoses, use of, 277
Hottest-spot temperature, 115
H.V. winding, 18

Hysteresis, 19
  loss, 16

I

Impedance voltage, 30-2
Impressed voltage, 19, 20
Inductive reactance in transformer, 27
Insulation materials, 65, 115-22
  classes, 116-17
Insulation resistance tests, 260
Interleaved joints, 68-9
Interphase barriers, 146
Iron loss, 20
  reduction, 24

J

Jack bolts, 72

K

kVA rating, 25

L

Labour protection, 274
Lacquer, nitrocellulose, 126
Laminated boards, 121
Laminations, 16
Leads, 65, 87
  arc welding, 175
  assembly, 210-22
  cleats, 89
  connection to flexible conductors, 206
  contact lugs, 206-06
  from round wire, 202
  manufacture, 196-203, 210, 216-17
  marking, 48
  polarity, 48, 50
  resistance welding, 176-78
  soft soldering, 175
  twisted, 202
  twisting tool for, 202
  types, 196,
Leakage flux, 18, 20, 27
Lifting gear, use of, 277
Lifting rods, 73
Load loss, 24
Locking strips, 149, 152
Looping tool, 212
Loss angle, 19
L.V. windings, 18

M

Magnesia cement, preparation, 238
Magnetic circuit, def., 14
Magnetic leakage, 30-2
  direct measurement, 30
Magnetic saturation, 19
Main magnetic flux, 17
Major insulation, 78
Maximum safe temperature, 59
Mechanical forces in transformer, 27, 32
Mechanical stresses, 33, 165
  radial, 145
Minor insulation, 78
Moving-coil voltage regulator, assembly, 166-73
  bushing installation, 236
  core-coil testing, 264
  design, 167
  lead assembly, 225
  packing out, 167-68
  tanking, 265
  top yoke reblading, 169
Multiple-layer winding, 74
Mutual magnetic flux, 17

N

Nippers, 131
No-load current, 17
No-load losses, 20
No-load vector diagram, 19

O

Off-circuit tap changer, 65
Off-circuit tap changing, 81
Oil-barrier insulation, 78-9
Oil conservator, 67, 103-04

Oil ducts, 79, 161
Oil filling operation, 264, 269
Oil level gauge, 67, 104-05, 254, 261, 268
    reflex type, 105
    window pattern, 105
Oil level marks, 272-73
Oil resistant transformer rubber, 125-26
Oil seal, 104
Oil thermometer, 67
On-load tap changing, 65
On-load voltage control, 65
Optional tests, 173

P

Packing material, 103
Packing out, 144-46, 155
Packing strips, 79
Paint, anti-condensate, 249
Painting, dipping method, 249
    flow method, 244, 249
    spraying method, 244-45
Painting booth, 246-49
Painting chamber, 246
Paintwork, 243
Parallel operation, requirements for, 53-58
Parasitic currents, 16
Phase displacement indication, 50
Pliers, 131
Porcelain, 122
Portable drills, 131-32
Pressboard, 117
Pressure rings, 72, 149
Primary, 18
    circuit, 14
    current, 14
Primer, 126
Punchings, 16

R

Radial forces, 35
Ratio adjuster, 65, 81
Reblading operation, 70
Relief stack, 67, 108
Rosin, 125
Rubber, transformer, 125-26

S

Safety in assembly shop, 275-76
Screwdrivers, 130
Secondary, 18
Secondary circuit, 14
    current, 14
    e.m.f., 14, 28
Self-protection of transformer, 27-9, 32
Shell-type core, 67-8
Short circuit,26
    current, 27
    voltage, 30
Side identification, 146
Silicon steel, 16
Single-layer winding, 74
Skinning, wire, 141
Slackness, elimination, 251
Soldering, fluxes, 124-25
    paste, 125
    safety, 276-77
    soft, of leads, 175
Solders, 124
Spanners, 130
Spiral winding, 75
Spray gun, 244
Spraying outfit, 244-45
Stampings, 16
Star connection symbol, 47
Step-down transformer, 18
Stripper, 211
Stud holes, 73
Synthetic-resin-bonded paper products, 122

T

Tank, 65, 98-9,
    preparation, 250
Tanking operation, 252, 261
    testing, 261
Telephone-cable paper, 118
Temperature at short circuit, 28
Temperature indicator, 109

Temperature rise of transformer windings, 59
Terminal bushings, 90
    assembly, 236-42
    built-up, 97, 236, 252, 254
    detachable, 95, 259
    flanged, 97
    indoor, 92, 238-39
    multiple mounting, 241
    outdoor, 92, 240-41
    plain type, 92
    shedded type, 92
Thermometers, 108-09
Three-phase transformation by single-phase units, 40
Three-phase transformer, 39-41
Three-winding transformer, 41-3
Tie-rods, 68, 72
Tongs, brazing, 180
Top yoke, reblading, 157-60
    unblading, 136-37
    unclamping, 134-36
Transformation ratio, 18
Transformer, 9, 13
    at no-load, 17
    efficiency, 25
    energy transfer in, 13
    operating principle, 13
    principal units, 9
    purpose of, 11
    step-down, 13
    step-up, 13
    under load, 21, 26
    useful power, 25
Transformer assembly, first stage, 9
    second stage, 9,10
    third stage, 9, 10
Transformer core, 16
Transformer insulation, 78-9
Transformer oil, 65, 121
Transformer steel, 16
Transformers in parallel, 50, 53-8
Transposition methods, 75
Truck, 65, 102
Tubular radiators, 100
Tubular tank, 99
Turns ratio, 17-8
Types of cooling systems, 60-62

U

Unblading, 70
Universal shear-punch-bar cutter 202
Useful power output, 32

V

Varnished cloth, 118-19
Varnishes, 119-20
Vector diagram under load, 22-3
Vector groups, 50-1, 53
Vernier calipers, 134
Voltage control, 37-9
    taps, 37-9, 78
Voltage drops in transformer, 28

W

Welded joints, soapsuds test, 236-37
Windings, 64, 73
    in core type transformer, 70
    types, 74-8
Wraps, 140, 142

Y

Yoke clamps, 72
Yoke insulation, 79, 142, 147
Yokes, 70
Yoke studs, 72

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